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PREFACE.

THE present volume contains ten papers presented at the Autumn General Meeting held in Middlesbrough on September 14th to 17th, 1937, together with the discussions and correspondence on them. The following two Special Reports :

Special Report No. 18.—"Reports upon Blast-Furnace Field Tests.—I.,"

Special Report No. 19.—"Foamed Blast-Furnace Slag," by T. W. PARKER,

were also presented, and the discussion to which they gave rise and the replies thereon are included in the present volume. A communication to the Proceedings of the Institute has been received, and this is likewise incorporated in Section I.

Corresponding to the alterations in the arrangement of Section I. effected in the No. I. volume of the *Journal* for this year, Section I. of the present volume has also been re-organised. This Section opens with the Minutes of Proceedings, including an account of the business sessions, works visits and entertainments during the Autumn Meeting held in Middlesbrough; then follow the papers and summaries of the Special Reports presented at the Meeting, together with the discussion and correspondence on them, and also a Communication to the Proceedings not presented at the Meeting. The Section concludes with biographical notes on deceased Members.

Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of the Iron and Steel Institute*, which is issued monthly.

In front of the title page is inserted a list of the British Standardised Steel Samples, issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship of the Institute will also be found in the same place.

28, VICTORIA STREET,
LONDON, S.W. 1.
December, 1937.

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ABBREVIATIONS USED IN THE TEXT.

Å.	Ångström unit(s).
A.C.	air-cooled; alternating current.
A.H.	air-hardened.
amp.	ampère(s).
amp.hr.	ampère-hour(s).
atm.	atmosphere(s) (pressure).
Bé.	Baumé (scale).
b.h.p.	brake horse-power.
B.o.T.	Board of Trade.
B.Th.U.	British thermal unit(s).
C.	centigrade (scale).
cal.	calory; calories.
c.c.	cubic centimetre(s).
c.d.	current density.
c.g.s.	centimetre-gramme-second unit(s).
cm.	centimetre(s).
coeff.	coefficient.
const.	constant(s).
c.p.	candle-power.
cu.	cubic.
cwt.	hundredweight(s).
D.C.	direct current.
dia.	diameter(s).
dm.	decimetre(s).
e.m.f.	electromotive force.
F.	Fahrenheit (scale).
ft.	foot; feet.
ft.lb.	foot-pound(s).
g.	gramme(s).
gal.	gallon(s).
H.F.	high-frequency.
h.p.	horse-power.
h.p.hr.	horse-power-hour(s).
hr.	hour(s).
in.	inch; inches.
in.lb.	inch-pound(s).
K.	absolute temperature (Kelvin scale).
kg.	kilogramme(s).
kg.cal.	kilogramme-calory; -calories.
kg.m.	kilogramme-metre(s).
km.	kilometre(s).
kVA.	kilovolt-ampère(s).
kW.	kilowatt(s).
kWh.	kilowatt-hour(s).
lb.	pound(s).
L.F.	low-frequency.
m.	metre(s).
m.amp.	milliampère(s).
mV.	millivolt(s).
max.	maximum.
mg.	milligramme(s).
min.	minimum; minute(s).
ml.	millilitre(s).
mm.	millimetre(s).
m.m.f.	magnetomotive force.
N.	normal (solution).
N.T.P.	normal temperature and pressure.
O.H.	open-hearth; oil-hardened.
O.Q.	oil-quenched.
oz.	ounce(s).
p.d.	potential difference.
*p*H	hydrogen-ion concentration.
r.p.m.	revolutions per minute.
sec.	second(s).
sp. gr.	specific gravity.
sq.	square.
T.	tempered.
temp.	temperature.
V.	volt(s).
VA.	volt-ampère(s).
Wh.	watt-hour(s).
W.Q.	water-quenched.
yd.	yard(s).
°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

AUTUMN MEETING

1937

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.), A.I.C., Assistant Secretary, in the preparation of this Section.

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MINUTES OF PROCEEDINGS, PAPERS AND DISCUSSIONS

AND

VISITS AND EXCURSIONS

AT THE

AUTUMN MEETING IN MIDDLESBROUGH, 1937.

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held in Middlesbrough from Tuesday to Friday, September 14th to 17th, 1937, at the cordial invitation of the Iron, Steel and Engineering Industries of Middlesbrough and the Cleveland district. Four hundred and three Members and a hundred and seventy-three Ladies took part.

An influential and representative Reception Committee had been formed to receive the visitors; it was composed of the following gentlemen:

GENERAL RECEPTION COMMITTEE.

Chairman:

Mr. BENJAMIN TALBOT, Cargo Fleet Iron Co., Ltd.

Vice-Chairman:

Mr. ARTHUR DORMAN, Dorman, Long & Co., Ltd.

Honorary Treasurer:

Mr. ASTLEY BARTON, The South Durham Steel & Iron Co., Ltd.

Honorary Secretary :

Mr. R. S. H. CAPES, Dorman, Long & Co., Ltd.

Members :

BELL, Sir MAURICE H. L., Bt., C.M.G.
BOWDEN, F. W., *President*, Cleveland Institution of Engineers.
BRIGGS, T. K., Tees-Side Chamber of Commerce.
BROWN, Ald. J. WESLEY, Tees-Side Chamber of Commerce.
CARTER, Councillor G., *Mayor*, Town Council of Middlesbrough.
CLARKE, F. P., Cargo Fleet Iron Co., Ltd.
COCHRANE, G. D., Richard Hill & Co., Ltd.
CONSTANTINE, W. W., Joseph Constantine Steamship Line, Ltd.
COWELL, R. E., *Secretary*, Cleveland Institution of Engineers.
CROSTHWAITE, W. H., Dorman, Long & Co., Ltd.
DAVIES, Alderman B. O., Tees-Side Chamber of Commerce.
DUNBAR, A., Darlington Forge, Ltd.
EDWARDS, A., M.P., Middlesbrough East.
FIELD, H. V., *Principal*, Constantine Technical College.
FLETCHER, F. S., Tees-Side Bridge & Engineering Works, Ltd.
FOX, E. J., Cochranes (Middlesbro') Foundry, Ltd.
GARSON, S. T., Gjers Mills & Co., Ltd.
GJERS, J., Gjers Mills & Co., Ltd.
GOODENOUGH, J. G., Dorman, Long & Co., Ltd.
GREENWOOD, THE RT. HON. VISCOUNT, P.C., K.C., Dorman, Long & Co., Ltd.
GRIFFITHS, C. KINGSLEY, M.P., Middlesbrough West.
HARRISON, J. H., Cleveland Institution of Engineers.
HARRISON, J. W., Darlington Rolling Mills Co., Ltd.
HEDLEY, G., Linthorpe Dinsdale Smelting Co., Ltd.
HUNTER, ELLIS, Peat, Marwick, Mitchell & Co.
HUTCHINSON, ALFRED, *President*, Iron and Steel Institute.
JACKSON, E. W., Pattinson and Stead.
JAMES, E. A., South Durham Steel & Iron Co., Ltd.
JOHNSON, W. L., Dorman, Long & Co., Ltd
KITCHEN, PRESTON, *Town Clerk*, Middlesbrough.
LEITH, P. A. R., Cleveland Institution of Engineers.
MCQUISTAN, A. N., Cargo Fleet Iron Co., Ltd.
MARR, L. E., London & North-Eastern Railway Co.
MILES, R., Head Wrightson & Co., Ltd.
MOFFETT, STANLEY, Director of Education.
NATTRASS, F. T., Tees Conservancy Commission.
OWSTON, J. E., Darlington Rolling Mills Co., Ltd.
PATON, A. M., North-Eastern Electric Supply Co., Ltd.
PEASE, Sir RICHARD, Bt., Pease & Partners, Ltd.
PEAT, C. U., M.P., Peat, Marwick, Mitchell & Co.
PEAT, J. B., Tees-Side Bridge & Engineering Works, Ltd.
RAMBUSH, N. E., Ashmore, Benson, Pease & Co., Ltd.
ROELOFSEN, J. A., Dorman, Long & Co., Ltd.
ROSS, D., Cargo Fleet Iron Co., Ltd.
SADLER, S. A., Sadler & Co., Ltd.
SAMUELSON, Sir FRANCIS, Bt., Tees Conservancy Commission.
SCHOLES, A., Pattinson and Stead.
SHAW, H. A., W. Shaw & Co., Ltd.
SHEPHERD, F., Dorman, Long & Co., Ltd.
SOUTHERN, J. H., Richard Hill & Co., Ltd.
SPIELMAN, C. M., Whessoe Foundry & Engineering Co.
STEEL, J. R., West Hunwick Silica and Firebrick Co., Ltd.
TALBOT, CHETWYND, Cargo Fleet Iron Co., Ltd.
TAYLOR, H. A., Cochranes (Middlesbro') Foundry, Ltd.
TAYLOR, J. FRATER, Pease & Partners, Ltd.
THORNTON, J. A., Skinningrove Iron Co., Ltd.
WHITWELL, W. F., Warner & Co., Ltd.
WHYTE, A., Skinningrove Iron Co., Ltd.
WILLIAMS, E., Linthorpe Dinsdale Smelting Co., Ltd.

WILLIAMS, ISAAC, Cargo Fleet Iron Co., Ltd.
WRIGHT, H. E., Dorman, Long & Co., Ltd.
WRIGHT, L. F., Gjers Mills & Co., Ltd.
WRIGHTSON, J. G., Head Wrightson & Co., Ltd.
WRIGHTSON, Sir T. G., Bt., Head Wrightson & Co., Ltd.
ZEALLEY, A. T. S., Imperial Chemical Industries, Ltd.

The details of the Meeting were arranged by an Executive Committee composed as follows :

EXECUTIVE COMMITTEE.

Mr. ASTLEY BARTON.
Mr. T. K. BRIGGS.
Mr. R. S. H. CAPES.
Councillor G. CARTER (Mayor).
Mr. W. H. CROSTHWAITE.
Mr. A. DORMAN.
Mr. H. V. FIELD.
Mr. J. G. GOODENOUGH.
Mr. G. HEDLEY.
Mr. A. HUTCHINSON.
Mr. PRESTON KITCHEN.
Mr. A. N. MCQUISTAN.
Mr. L. E. MARR.
Mr. F. T. NATTRASS.
Sir FRANCIS SAMUELSON, Bt.
Mr. C. M. SPIELMAN.
Mr. J. R. STEEL.
Mr. B. TALBOT.
Mr. A. WHYTE.
Mr. A. T. S. ZEALLEY.

Mr. J. R. Steel was Chairman of the Sub-Committee which assumed responsibility for entertainment and the social functions, and Mr. L. E. Marr was Chairman of the Sub-Committee on Transport. The work of these two Sub-Committees contributed greatly to the success of the Meeting.

A Ladies' Committee was formed on which the following Ladies kindly agreed to serve :

LADIES' COMMITTEE.

Mrs. G. CARTER (Mayoress).
Mrs. W. H. CROSTHWAITE.
Mrs. A. DORMAN.
Mrs. J. G. GOODENOUGH.
Mrs. GUTHRIE.
Mrs. G. HEDLEY.
Miss P. JOHNSON.
Mrs. A. N. MCQUISTAN.
Mrs. J. R. STEEL.
Miss TALBOT.
Mrs. A. WHYTE.

Mr. Benjamin Talbot, Chairman of the Reception Committee, was taken ill shortly before the Meeting, and was therefore, to the general regret, unable to be present until the last day. Members were very pleased to find that his recovery had been sufficiently rapid to enable him to receive them at the garden party at his house—Solberge Hall—on the Friday afternoon.

The Council wish to take this opportunity of expressing thanks on behalf of themselves and the Members to Mr. Benjamin Talbot, Mr. Arthur Dorman and the Members of the Reception Committee; to His Worship the Mayor of Middlesbrough and the Municipal Authorities; to the owners of Works in the Iron, Steel and Engineering Industries of Middlesbrough and the Cleveland District; to the Authorities of the Constantine Technical College and the Cleveland

Scientific and Technical Institute; to the London and North-Eastern Railway, the Tees Conservancy Commissioners and to the many others whose help was freely and generously given. The results of their labours was a visit of great interest for which every possible detail had been foreseen and provided for, and which will long be remembered by those taking part as one of the most successful Autumn Meetings of the Institute.

The Secretaries' Office was opened on the afternoon of Tuesday, September 14th, in a room at the Constantine Technical College, Borough Road, Middlesbrough, for the registration of Members and for the distribution of programmes, badges, tickets, &c. On the following morning it was moved to the Cleveland Scientific and Technical Institute, Corporation Road, where the Technical Sessions were held on the Wednesday and Thursday mornings.

TUESDAY, SEPTEMBER 14TH.

At 9 P.M. on Tuesday, September 14th, His Worship the Mayor of Middlesbrough (Councillor G. Carter) and the Mayoress received the visitors on behalf of the Corporation of Middlesbrough at the Constantine Technical College; many of the Departments of the College were thrown open for inspection to enable the Members to gain some insight into its activities. Many Members and Ladies participated and a successful and crowded reception was followed by dancing.

WEDNESDAY, SEPTEMBER 15TH.

The Opening Session of the General Meeting was held in the Cleveland Scientific and Technical Institute on Wednesday morning at 10 A.M. In the absence of Mr. Benjamin Talbot, Mr. Arthur Dorman, Vice-Chairman of the Reception Committee, took the Chair. His Worship the Mayor of Middlesbrough, the Mayoress and Members of the Reception Committee were present on the platform to give the visitors a hearty welcome.

CIVIC WELCOME.

His Worship the MAYOR OF MIDDLESBROUGH (Councillor G. Carter), who was accompanied by the Mayoress, welcomed the Institute on behalf of the City. He could not, he said, express too highly the pleasure which it gave him to do so. The people of Middlesbrough were delighted that the Institute had chosen their town for its Autumn Meeting, and very much appreciated the honour thus conferred upon it.

Middlesbrough as an industrial town had always been in the forefront of progress in matters relating to the iron and steel industry. There might be present that morning some who had not visited

Middlesbrough during recent years. On their tours of inspection they would, he thought, see vast changes in the industries of the town and district. Those changes had created problems for the town, through the mechanisation of industry and the displacement of labour, and, although loss of employment was to be regretted, he had not the slightest doubt that such changes were necessary for economic productive purposes.

The continued prosperity of the iron and steel industry in Middlesbrough was what they all had at heart. It was their main concern, as it was vital to the community; if there was a slump in the iron and steel trade—and he hoped that there would never be another—everyone was affected, because unemployment threw more people on public assistance and thereby more public money was spent, with a consequent increase in the rates. He was glad that on the occasion of the Institute's visit the industry was showing a wonderful recovery. Unfortunately the problem of unemployment still remained, and, though it was less acute now than it had been for some years past, there were still approximately seven thousand unemployed in the town.

In the year 1862, Middlesbrough was visited by that eminent statesman, Mr. W. E. Gladstone, whose reputation for wise sayings was well known. He then described Middlesbrough as "the youngest child of England's enterprise. An infant Hercules." The citizens of the town recalled with satisfaction that some of the greatest pioneers of the iron and steel industry had been Middlesbrough men, and had held the position of President of the Iron and Steel Institute. He referred to Sir Lowthian Bell (1873–75), the Rt. Hon. Sir Bernhard Samuelson (1883–85), Mr. Edward Windsor Richards (1893–95), Sir Hugh Bell (1907–10), Dr. Arthur Cooper (1912–14), Dr. John Edward Stead (1920–22), Mr. Francis Samuelson (1922–24) and Mr. Benjamin Talbot (1928–29), and they were delighted that the present President of the Institute was another Middlesbrough man, Mr. Alfred Hutchinson. (*Applause.*)

The local industries had many outstanding achievements to their credit, and he would like to say how immensely proud they were of the fact that the world-renowned Sydney Harbour Bridge had been erected by the Middlesbrough firm of Messrs. Dorman, Long & Co., Ltd. The bridge stood as a permanent example of the skill and enterprise of local engineers. In addition to the many other engineering feats accomplished by this firm, he saw that they had recently completed a bridge in Denmark to be opened on September 26th next by King Christian of Denmark. This bridge was one of the longest and largest in the world, and had taken four years to build.

As the Institute had met the previous day in the Constantine Technical College, he would like to say that it was through the generous gift of the late Mr. Joseph Constantine and his family, who provided £80,000 towards the cost of the building, that these

facilities for technical education were available. To that gift a further £26,000 had been added by local firms and individuals. The College provided training chiefly for students in metallurgy, engineering and chemistry. It was opened by H.R.H. the Duke of Windsor (then Prince of Wales) in 1930.

The municipality had always been alert in providing for the needs of the industries of the district. There was an abundant water supply, which even in the worst droughts had never caused any concern to the industries. The municipality had provided about four thousand dwellings for the working classes. It supplied gas at a cheaper rate than any other town in the country—those who visited the council chamber would realise that gas was always in evidence (*laughter*)—and had a most efficient and economical supply of electricity. Although Middlesbrough was an industrial town, there were many delightful residential areas within the borough and its immediate neighbourhood. A few minutes by motor brought one to some of the prettiest scenery in the country—the Cleveland moors and district. As the Members of the Institute and their Ladies were to visit several of these beauty spots, he could only hope that they would be favoured with fine weather, so that they might enjoy the beauties of the town and surrounding country to the full.

In the name of the municipality of the great Tees-side county borough of Middlesbrough, he extended to all the Members of the Institute and their Ladies a hearty and sincere welcome to the town. He trusted that the meetings would be of great value, and that when the visitors left for their homes they would retain very vivid and happy recollections of their stay in Middlesbrough. (*Applause.*)

Welcome on Behalf of the Reception Committee.

Mr. Arthur Dorman expressed his regret that, owing to ill health, Mr. Talbot, the Chairman of the Reception Committee, was unable to be present. It had therefore fallen to himself, as Vice-Chairman of the Committee, to support the Mayor of Middlesbrough in extending a hearty welcome to their guests and to express the hope that they would enjoy their visit to Tees-side. They would all, he was sure, sympathise with Mr. Talbot, who had been looking forward to the visit of the Institute and had taken an active part in making the necessary arrangements. Mr. Talbot was a Past-President of the Institute, and as the inventor of the Talbot process his name stood high in the metallurgical world. (*Applause.*) It was to be hoped that he would be able to receive his guests on Friday at the garden party which he was so kindly giving at his house.

If the weather was kind during the next day or two, it would be possible to show the Ladies and others who went on the excursions some beautiful scenery, some of it of historic interest, and, though the people of the district were modest, they could show useful and

well-equipped iron and steel works to the critical eyes of the many technical persons who had honoured them by their presence.

It was twenty-nine years since Middlesbrough had last entertained the Iron and Steel Institute. At that time, the basic open-hearth process had gradually but surely to a large extent superseded the acid open-hearth process. As a young man, he had always been impressed by the energy with which his father—Mr. A. J. Dorman, as he was then—had accelerated that change-over at the Britannia Works of Dorman, Long & Co., and, in conjunction with the late Sir Hugh Bell, who was then President of the Institute, had built the Clarence Steelworks for the special purpose of making steel from Cleveland pig iron. At that time, scrap and hematite iron were usually 10*s.* a ton more expensive than Cleveland iron, and that difference in price made his father determine to overcome the difficulties, which in those days were very real, partially owing to the unsuitable quality of the iron, the only choice being high silicon or high sulphur, and partially owing to the smallness of the steel furnaces themselves. The Talbot process was then becoming a power in the land, and, as was well known, Mr. Talbot even in those early days went in for the large tilting furnaces, which no doubt did overcome some of the initial difficulties. Those who visited the Cargo Fleet Works would see the modern development of that process, while the large tilting furnaces at the Acklam Works and at Skinningrove were very similar to the original furnaces designed by Mr. Talbot. That much-discussed process, the basic Bessemer, the sport of the modern politician (*laughter*), was then dying a lingering death in the Middlesbrough district, where it had been invented.

Altogether, the year 1908 could be described as a transition period of a most interesting description. Much had happened since then. Many well-known firms had disappeared, chiefly owing to amalgamations. Fewer blast-furnaces were in operation, and the Clarence Iron and Steel Works were no more. The outputs of the furnaces which still remained, however, were considerably higher, and the district still maintained a prominent position in the iron and steel trade of the world; and once again a prominent local man was President of the Institute. (*Applause.*) It was largely due to the enterprise of Mr. Hutchinson's father, the late Mr. J. C. Hutchinson, that the Skinningrove Steelworks had come into being.

Lord Greenwood, in an article on "Tees-side in the Iron and Steel Revival" which had appeared in a local paper, the *North-Eastern Daily Gazette*, two days previously, had described the position to-day as a transition period, since many works were in a state of transition from old to new plant and equipment. Personally, he thought that no one could visualise any finality in that direction, especially at a meeting such as he was addressing, at which there were present so many people who, he felt sure, were full of new inventions and ideas for new processes.

It was a great pleasure to see so many prominent people connected with the iron and steel trade present, and also to welcome so many Ladies. He would like, as Vice-Chairman of the Reception Committee, to thank the Mayor and the Town Clerk of Middlesbrough for the ready help which they had given, and also to thank the many willing workers who had been responsible for carrying through the arrangements for the Institute's visit. He hoped that when the visitors went away they would take with them a good impression of the iron and steel works of the district. They could be sure of this, that those who came from other countries and from other districts would carry away with them the best wishes of all on Tees-side for their prosperity, especially as those on Tees-side, who were not altogether unmindful of their own interests, felt that the prosperity of their visitors should mean their own prosperity also. (*Applause.*)

The President's Reply to the Welcome.

The President (Mr. Alfred Hutchinson), in reply, said that on behalf of all the Members of the Iron and Steel Institute who were attending its fourth Middlesbrough Meeting, he would like to tender sincere thanks to the Mayor and to Mr. Dorman for the very warm welcome which they had extended and for the very full programme of meetings, visits and social functions which they and all the Members of the Reception Committee had so kindly arranged for the enjoyment of their visitors. In the preface to the Programme, the Council of the Institute had expressed their thanks, and he endorsed every word of that preface.

It was twenty-nine years since the Institute had last visited Middlesbrough. To-day they were living in a new world, with new industrial and social conditions, most of the changes being based upon the results of research in every department of life. The Iron and Steel Institute played a leading part in the researches necessary for the development of an industry which was of the first importance to the national welfare.

The Members were looking forward very eagerly to the discussions on the papers, and especially on those dealing with processes which had their origin in the Middlesbrough district, and also to the visits to the various works, in which so much had been done to modernise and equip them for the increased demands which were being made upon steelmakers all over the world. They thanked their hosts most sincerely for inviting them to hold the Autumn Meeting in Middlesbrough and for the alluring programme which had been prepared for them in every possible direction.

He would like to add that personally he was profoundly grateful that the Institute had been invited during his year as President to hold its Autumn Meeting in the district in which he had spent most of his life. The present Meeting was being held in the hall of

the Cleveland Scientific and Technical Institute in Corporation Road. He himself was born in Corporation Road, and as a child he had looked across green fields in front of his home, but ere long preparations had been made for the erection of the building in which the Institute was now meeting, and his earliest recollection was of friendly relations with the stonemasons who dressed the stonework for it. Opposite the door of the building was the iron gate of the dame's school which he attended, and where he had his first romance. (*Laughter.*) He remembered holding the gate fast and exacting the toll of a kiss from the girls of his choice; and he need hardly say that they grew up to be the three most beautiful girls in the town. (*Laughter.*) He little thought then that, some sixty-five years afterwards, he would be replying to an address of welcome as President of an Institute of such world-wide repute as the Iron and Steel Institute.

It was a peculiar pleasure to him that, although many who were captains of industry in the district in 1908 were no longer living, Mr. Talbot, who had played such an important part in the development of the basic open-hearth process all over the world, was still active, although to the general regret he was unable to be present that morning owing to ill health. He was very pleased to see as his substitute Mr. Arthur Dorman, the Vice-Chairman of the Reception Committee, the worthy son of Sir Arthur Dorman, who had done so much to develop the basic open-hearth process in the district and who had started the structural steel trade, which had become such an important part of the activities of the district as a whole. (*Applause.*)

He would conclude his brief reply by again tendering to the Mayor and to Mr. Dorman the thanks of all the Members attending the Autumn Meeting in Middlesbrough.

Formal Business.

At the conclusion of the speeches of welcome His Worship the Mayor and the Mayoress left the Meeting and Mr. Arthur Dorman vacated the Chair, which was taken by the President, Mr. Alfred Hutchinson, M.A., B.Sc.

The Minutes of the last General Meeting were taken as read and confirmed.

Ballot for the Election of New Members and Associates.

Mr. W. E. Hoare (London) and Mr. I. M. Pryse (Rotherham) were appointed scrutineers of the ballot for the election of new Members and Associates, and in due course they reported that the following one hundred and fifty-six Members and thirty-six Associates had been elected :

Members.

ADKINS, REX	Coventry.
ALLEN, NORMAN PERCY, D.Sc.	Birmingham.
ALLEN, THOMAS	Kingswinford, Staffs.
ALSOP, RALPH	Black-Hill, Co. Durham.
ATKINS, WILFRID ARTHUR	Hayes, Middlesex.
AUBERT, HENRI	Gueugnon (Saône-et-Loire), France.
BAILEY, RICHARD WILLIAM, D.Sc.	Manchester.
BAMFORD, THOMAS G.	Wednesbury.
BARHAM, RONALD JACK, B.Sc.	Junin, Argentina.
BARKWELL, BERNARD	Sheffield.
BILLINGHURST, PHILIP EDWARD	Salisbury, Southern Rhodesia.
BISHOP, WILLIAM WARNER, A.M., Litt.D., LL.D.	Ann Arbor, Mich., U.S.A.
BROADFOOT, ERIC HENRY	Birmingham.
BRONIEWSKI, WITOLD	Warsaw, Poland.
BROWN, *Engineer Vice-Admiral* Sir HAROLD	London.
BUCHANAN, JOHN GRAY, J.P.	London.
BURN, ROBERT	Wellington, New Zealand.
BURSTALL, AUBREY FREDERIC, M.Sc., Ph.D.	Carlton, Victoria, Australia.
CAMPBELL-PRESTON, R.	Middlesbrough.
CAPLAN, BERNARD	Bromley, Kent.
CAPLAN, MAURICE CYRIL, B.Sc. (Met.)	Wembley, Middlesex.
CELLAN-JONES, GWYNNE	Middlesbrough.
CHASTON, JACK CHAMBERS, B.Sc. (Lond.), A.R.S.M.	Newton Mearns, Renfrewshire.
CHRISTMAS, REGINALD EUSTACE	London.
CLARK, H. W.	London.
CLAVEY, GILBERT AUSTIN	Manchester.
COOPER, LANCELOT BOWSER	Middlesbrough.
CURNOW, HUGH JOHN, B.Sc. (Hons.) London	London.
DAVENPORT, JAMES WALTER	Jamshedpur, India.
DAWE, REGINALD WILLIAM	Swindon, Wiltshire.
DELORI, JEAN	Ghent, Belgium.
DEVEREUX, WALLACE CHARLES, F.R.Ae.S.	Slough, Buckinghamshire.
DREWERY, ERIC	Redcar, Yorkshire.
DUNLOP, *Mrs.* EDITH FRIDA, B.Sc. (Met.) Glasgow	Hong Kong.
DYSON, ARTHUR, M.Inst.C.E.	Tipton, Staffordshire.
EDMUNDSON, C. D.	Napier, New Zealand.
ENGEL, WALTER	Copenhagen, Denmark.
EVANS, HERBERT	Gorseinon, Glamorganshire.
FALK, ERIK	Västeras, Sweden.
FEATONBY, HORACE	Redcar, Yorkshire.
FOCKE, ARTHUR E., Ph.D.	Indianapolis, Indiana, U.S.A.
GANDOLFO, JOSÉ S.	Buenos Aires, Argentina.

GIBBONS, ALFRED CHARLES, M.C., B.Com.	Bristol.
GIERDZIEJEWSKI, CASIMIR	p. Ursus k/Warszawy, Poland.
GOUGE, ARTHUR, B.Sc., F.R.Ae.S.	Rochester.
GRAHAM, JOHN AIDAN	Sheffield.
GRAY, KENNETH	Sheffield.
GREINER, ALLEN	London.
GROVES, CLARENCE RICHARD, M.Sc., A.I.C.	Middlesbrough.
GURNEY, NORMAN RICHARD DAWSON, A.C.H.I., A.M.I.E.E.	Manchester.
HALL, STAFFORD	Leeds.
HARGREAVES, FRANK, A.R.S.M., D.I.C., F.I.C.	Eastleigh, Hampshire.
HARRIS, HARRY EDWIN, M.I.Mech.E.	Oldham, Lancashire.
HENTSCHEL, *Dr. Ing.* ROLF	Düsseldorf, Germany.
HILLS, REGINALD JOHN	Eastleigh, Hampshire.
HINDSON, WILLIAM ABNER	Redcar, Yorkshire.
HINTON, ERIC AUSTIN	Coventry.
HOLDEN, JOHN WILLIAM, B.Met.	London.
HOLDENGARDE, THEODORE ALBERT EDWARD.	Bulawayo, Southern Rhodesia.
HOUGHTON, JOHN WARLOW, Assoc. Met.	Rotherham.
HOWARD, EDWARD JOHN LEES	Wilmslow, Cheshire.
IFOULD, W. H.	Sydney, N.S.W., Australia.
IZOD, E. G.	Addlestone, Surrey.
JACK, ALEXANDER JOHN, B.Met. (Sheffield)	Sheffield.
JENKS, FRANK	Newcastle, N.S.W., Australia.
JEVONS, JOHN DUDLEY, B.Sc., Ph.D., A.I.C.	Birmingham.
JUDGE, EDWARD THOMAS	Middlesbrough.
JUHLIN, GUSTAF ADOLF, M.I.E.E.	Manchester.
KAUL, MAHENDRA KISHAN, B.A. (Hons.)	Bombay, India.
KEENER, SAMUEL FLOYD	Salem, Ohio, U.S.A.
KENNETT, STANLEY JOHN	Liverpool.
KENRICK, JOHN TIMOTHY	Birmingham.
KINNEAR, JAMES WESLEY, jun.	Munhall, Pa., U.S.A.
KIRKWOOD, DAVID, jun.	London.
LAMB, RICHARD, A.M.I.Mech.E.	Sheffield.
LAMBILLIOTTE, ANDRÉ ALPHONSE JOSEPH EMILE	Louvière, Belgium.
LAYBOURNE, ELLIOT ANGUS	Springwell, Co. Durham.
L'ESTRANGE, W. M. E.	Brisbane, Australia.
LEVY, *Dr.* DONALD MYER	London.
LORANT, HUGO	London.
MACHALSKI, JOZEF	Dyrekcyjna, Poland.
MCLEOD, ALASTAIR	London.
MADAN, MEDIOMAH DHANHISHAH, B.Sc. (Bombay)	Jamshedpur, India.
MALCOLM, IAN COLQUHOUN	Redcar, Yorkshire.

MALKOVSKY, *Ing.* JAROSLAV A., D.Sc.	Prague-Liben, Czechoslovakia.
MARSHALL, DOUGLAS FREDERICK, B.Sc. (Tech.), Ph.D.	Rotherham.
MILLER, HERBERT JOHN, M.Sc.	London.
MOORE, CHRISTOPHER EDWARD	Bewdley, Worcestershire.
MOSS, FRED, B.Sc. (Hons. Met.)	Birmingham.
MOSTART, GASTON	London.
MURPHY, ALFRED JOHN, M.Sc.	London.
NEWTON, LEONARD OWEN	London.
NIELSEN, HERMAN, B.Sc., A.M.I.E.E.	Four Oaks, Warwickshire.
NOWELL, CHARLES, F.L.A.	Manchester.
ODGERS, ALBERT GARFIELD, M.A., D.Sc.	Wolverhampton.
OGILVIE, JAMES ALEXANDER	Pittsburgh, Pa., U.S.A.
ORAM, JOHN EDWARD	Potters Bar, Middlesex.
ORTLEPP, JULIUS ADOLPH LEOPOLD, M.Sc.	Pretoria, South Africa.
OWSTON, JOSEPH EDWARD	Darlington, Co. Durham.
PANSERI, *Dott. Ing.* CARLO	Milan, Italy.
PARKER, THEODORE HENRY GEORGE	Kingston-on-Thames, Surrey.
PARKYN, RODERICK WILLIAM, M.A. (Cantab.)	Alderley Edge, Cheshire.
PATTERSON, *Rear-Admiral* JULIAN FRANCIS CHICHESTER	Worksop, Nottinghamshire.
PERCIVAL, LESLIE CHARLES, B.Sc., B.Met.	London.
PHIL, STIG GUNNAR H:SON	Stockholm, Sweden.
PHILLIPS, HENRY WILFRED LEWIS, B.A. (Cantab.), A.I.C.	Warrington.
PIETSCH, ERICH, *Dr. Phil.*	Berlin, Germany.
POOLE, HERBERT FREDERICK	Keighley, Yorkshire.
POTTER, GEORGE LEE	London.
POWER, ARTHUR EDWARD, B.Sc. (Eng.) London	London.
PROOS, *Ir.* CORNELIS FREDERIK	Delft, Holland.
REBBECK, FREDERICK ERNEST	Belfast, Ireland.
RICHARDSON, WALTER, B.Sc. (Tech.), A.M.I.E.E.	Newcastle-upon-Tyne.
ROBERTSON, NEIL DOUGLAS GORDON	London.
ROBSON, STANLEY, M.Sc., D.I.C., M.I.M.M., M.I.Chem.E.	Bristol.
ROLLA, *Professor* LUIGI	Genoa (S. Martins), Italy.
ROTHSCHILD, MAX	Frankfurt am Main, Germany.
RYDER, DANIEL GRAHAM	London.
RYLANDS, *Lieut.-Commander* GEOFFREY KIRKLAND, R.N.	Warrington.
SANDERS, ALEXANDER	Bristol.
SCHANE, PHILIP, jun.	Youngstown, Ohio, U.S.A.
SEMPLE, DAVID RODDIL	Redcar, Yorkshire.
SHEPHERD, FRANK	Middlesbrough.
SHEPHERD, HORACE HENRY	Ipswich, Suffolk.
SLICK, FRANK F.	Braddock, Pa., U.S.A.

SMITH, CECIL HILL, B.Sc. (Eng.) Lond., G.I.Mech.E.	London.
SMITH, HARRY	London.
SMITH, RALPH DOUGLAS	Bengal, India.
SNEDDON, ROBERT	Bengal, India.
STOCKDALE, DAVID, M.A., Ph.D. (Cantab.), A.I.C.	Cambridge.
SWARTZ, CARL E.	Cleveland, Ohio, U.S.A.
SWARUP, *Professor* DAYA	Benares, India.
TASKER, EDWARD ERNEST, M.I.E.E., M.I.Mech.E.	London.
THOMAS, FREDERICK ARTHUR	London.
THOMAS, RICHARD EMRYS	London.
THOMSON, THOMAS JOSEPH LAMBTON	Oldbury, Worcestershire.
TINKER, GEORGE PARKER, M.Sc.	Birmingham.
TUCKER, HORATIO MIDDLETON	Swansea.
TURNBULL, REUBEN STANLEY	Saltburn-by-the-Sea.
ULMKE, *Dipl. Ing.* WALTER	Menden, Germany.
UPTON, ALFRED ERNEST	Sheffield.
VAN HOESEN, HENRY BARTLETT, Ph.D.	Providence, R.I., U.S.A.
VICKERS, GEORGE WESTLAKE	Sheffield.
WAINE, ARTHUR HENRY, A.I.Mech.E.	Sheffield.
WALSHAW, HARLAND R. B.	Scunthorpe, Lincolnshire.
WARREN, *Miss* ALTHEA	Los Angeles, California, U.S.A.
WEAVER, WILLIAM JAMES	Middlesbrough.
WHITEHEAD, ERIC JAMES	Allestree Park, Derby.
WILLIAMS, HAROLD WILFRED	Stroud, Gloucestershire.
WILLIAMS, STANLEY VAUGHAN, B.Sc. (Hons.)	Kenton, Middlesex.
WILSON, JAMES WILLIAM WALTER	Birmingham.
WIMPENNY, LEONARD	Widnes, Lancashire.
WISKAR, ERASMUS CHARLES VANE	Redcar, Yorkshire.
WISKAR, FRANK RAYMOND	Middlesbrough.
WLODEK, TADEUSZ	Lwów, Poland.
WRAGG, ARTHUR	Newcastle-upon-Tyne.

Associates.

ASPINALL, HAROLD MITCHELL	Sheffield.
BAKER, WILLIAM ALBERT	London.
BALL, F. A.	Birmingham.
BASFORD, JOHN LEONARD	Sheffield.
BEVAN, JOHN LEWIS MAYBERY	Neath, Glamorganshire.
BOOTH, ERNEST	Sheffield.
BRADLEY, ALAN LUDWIG	Worksop, Nottinghamshire.
BRIMELOW, ERNEST IRVING	Farnborough, Hampshire.
BROOK, HENRY DRONFIELD	Sheffield.
CAMPBELL, DONALD LE STRANGE	Weybridge.
CATHCART, DAVID	Glasgow.
FLEMING, BASIL ANTHONY	Scunthorpe, Lincolnshire.
HALAHAN, GEORGE EDWARD DESMOND	Scunthorpe, Lincolnshire.
HARGREAVES, ROGER	Cambridge.

HOWIE, THOMAS WYI LIE . .	Falkirk, Stirlingshire.
HOWSON, HAROLD OTTER . .	Sheffield.
KING, FRANK	Banbury, Oxfordshire.
LENTON, KENNETH WILLIAM . .	Coventry.
MILNES, AUBREY HENRY, B.Sc. (Hons. Met.)	Sheffield.
NEWMAN, ERNEST GEORGE VINCENT	London.
NIX, ERNEST	Rotherham.
OMODEI, C. T.	Sydney, N.S.W., Australia.
PEARSON, ANDREW . . .	Motherwell.
PRENTICE, DOUGLAS ROBERT CAMPBELL	Doncaster.
PRICE, LAURENCE ERNEST . .	Cambridge.
PYE-SMITH, A. T.	Beckenham, Kent.
RODGERS, FRED	Sheffield.
RUSSELL, FRANK WILLIAM FISHER .	Sheffield.
SEMLER, PETER E. . . .	Pilsen, Czechoslovakia.
SHAW, ZIANG-WA	London.
TURRELL, PETER	Sheffield.
VAUGHAN, NOEL BODIN . . .	London.
WHITNEY, GEORGE S. . . .	Sydney, N.S.W., Australia.
WHITWAM, JAMES TREVOR EDWIN .	Sheffield.
WORNER, HILL WESLEY . .	Melbourne, Victoria, Australia.
WORNER, HOWARD KNOX . .	Melbourne, Victoria, Australia.

Nomination of President for 1938.

The PRESIDENT (Mr. Alfred Hutchinson) reminded the Members that he had taken office for one year only, and that the Rt. Hon. the Earl of Dudley, M.C., had been nominated for election as President in succession to him, to take office at the Annual General Meeting, 1938.

Members of Council Retiring in 1938.

The SECRETARY (Mr. K. Headlam-Morley), in accordance with Bye-Law 10, announced that the following Members of Council were due to retire in rotation at the next Annual Meeting; they would be eligible for re-election. *Vice-Presidents:* Dr. C. H. Desch, F.R.S.; Mr. Arthur Dorman; Mr. H. Spence Thomas. *Members of Council:* Dr. T. Swinden; Dr. A. McCance; Mr. P. B. Brown; Mr. A. O. Peech; Captain H. Leighton Davies.

General Meetings, 1938.

The PRESIDENT announced that the Annual General Meeting of the Institute would be held in London on May 4th to 6th; it would include two days which would be devoted to a Symposium on Steelmaking, with special reference to Open-Hearth Practice. For this purpose a series of papers on the acid and basic open-hearth processes had been invited from each of the chief steel-producing districts of the country, with a view to information being supplied on differences in practice in different districts, the

nature of the problems in steelmaking which had been encountered, as well as the way in which they had been overcome. It was hoped that an indication would be given of the directions in which further research was required.

He also reminded the Members that a very cordial invitation had been received from the American Institute of Mining and Metallurgical Engineers and the American Iron and Steel Institute to hold the Autumn Meeting in 1938 in America jointly with the Institute of Metals; this invitation had been gladly accepted. A provisional programme had been prepared and full information would be issued as soon as it was available. He hoped that a large party of Members and their Ladies, representing all countries in which the Institute had Members, would take the opportunity of visiting the United States of America.

Obituary.

The PRESIDENT (Mr. Alfred Hutchinson) said that he was sure the Members would learn with deep regret of the death on the 14th September, 1937, of His Excellency Professor T. G. Masaryk, the Liberator and former President of the Czechoslovak Republic, who had honoured the Institute by becoming an Honorary Member of the Institute in 1930. Those who had taken part in the Autumn Meeting of the Institute in Czechoslovakia in that year would remember the splendid assistance and welcome which he had given on that occasion.

He would also remind them that the Right Hon. John Hodge had died on 10th August, 1937. At a meeting of the Institute it was unnecessary to refer to the remarkable work which Mr. Hodge had done on behalf of the workmen employed in the iron and steel industry. Mr. Hodge was the first Minister of Labour, and was one of the founders of the men's union, the Iron and Steel Trades Confederation. He was a man of the most striking personality to whom the labour side of the industry owed a debt of gratitude which it would be difficult adequately to express.

Those present at the Meeting stood in silence as a sign of respect.

Presentation of Papers.

The following Report and papers were then presented for discussion :

" REPORTS UPON BLAST-FURNACE FIELD TESTS. I.—An Investigation of a Blast-Furnace Smelting principally Lincolnshire Ores at the Frodingham Works of the Appleby-Frodingham Steel Co., Ltd." By the Blast-Furnace Reactions Sub-Committee of the Iron and Steel Industrial Research Council. (*Special Report No.* 18.)

F. W. HARBORD, C.B.E. : " The Thomas-Gilchrist Basic Process, 1879–1937."

W. GEARY : " Hot Metal Practice in Five Melting Shops on the North-East Coast."

Complete List of Reports and Papers Presented at the Autumn Meeting in Middlesbrough, 1937.

"Reports upon Blast-Furnace Field Tests. I.—An Investigation of a Blast-Furnace Smelting principally Lincolnshire Ores at the Frodingham Works of the Appleby-Frodingham Steel Co., Ltd." By the Blast-Furnace Reactions Research Sub-Committee of the Iron and Steel Industrial Research Council. (*Special Report No.* 18.)

"Foamed Blast-Furnace Slag." By T. W. Parker. (Being a Report of the Slag Tests Panel to the Blast-Furnace Committee of the Iron and Steel Industrial Research Council). (*Special Report No.* 19.)

H. E. Blayden, W. Noble and H. L. Riley: "Some Experiments in a Small-Scale Cupola."

H. E. Blayden, W. Noble and H. L. Riley: "The Influence of Carbonising Conditions on Coke Properties. Part I.—Mechanical Pressure."

M. S. Fisher and Z. Shaw: "The Mechanism of Nitride-Hardening."

W. Geary: "Hot Metal Practice in Five Melting Shops on the North-East Coast."

F. W. Harbord, C.B.E.: "The Thomas-Gilchrist Basic Process, 1879–1937."

W. E. Hoare: "Variation in Thickness of the Tin Coating of Tinplate, and its Effect on Porosity."

C. H. M. Jenkins, E. H. Bucknall, C. R. Austin and G. A. Mellor: "Some Alloys for Use at High Temperatures. Part IV.—The Constitution of the Alloys of Nickel, Chromium and Iron."

B. Jones: "Further Experiments on the Nitrogen-Hardening of High-Chromium and Austenitic Steels."

N. J. Klärding: "A New Method for Judging the Behaviour of Iron Ores during Reduction."

Richard R. Sillifant: "Some Notes on Recent Experiments in Connection with the Spraying of Steel by the Wire-Fed Metal-Spraying Pistol."

Communication:

G. C. Richer: "Note on the Influence of Grain Size on Magnetic Hysteresis."

At 12.30 P.M. the meeting was adjourned until the following morning.

The Ladies who were present at the opening ceremony left the Meeting Hall at the conclusion of the speeches of welcome and paid a visit to various places of interest in Middlesbrough, returning to the Town Hall at 12.30 P.M.

Visits and Entertainments for Members and Ladies.

On Wednesday the Members and Ladies were entertained to lunch in the Town Hall, Middlesbrough, by invitation of the Mayor of Middlesbrough (Councillor G. Carter) and the Chairman and Members of the Reception Committee; Mr. A. Dorman presided.

The Loyal Toast having been honoured, the Right Hon. THE VISCOUNT GREENWOOD, P.C., K.C., proposed the toast of "Success to the Iron and Steel Institute."

In doing so, he first expressed his regret at the absence of Mr. Talbot through illness. Mr. Talbot's name and career, he said, stood for much that was fundamental and successful in the great industry of iron and steel, and everyone would join in wishing him an early and happy recovery to his usual vigorous health. (*Applause.*)

He had the honour to propose the toast of "Success to the Iron and Steel Institute," and to couple with it the name of Sir William Larke, who had long and faithfully served the best interests of the steel industry. (*Applause.*) To do so was a great honour, and he knew that it came to him because he happened to be Chairman of Dorman, Long, which he considered the greatest achievement of his life. He was also a member of the Reception Committee, and as such he would like to express his sincere thanks to those persons—they could not possibly be steelmakers or men—who had decorated the town hall and added chandeliers. It must be the only town hall in the country with chandeliers—a feminine touch for which everyone would be grateful.

He could assure the Iron and Steel Institute that the Reception Committee and everyone on Tees-side welcomed those attending the meeting with the utmost goodwill. The Reception Committee controlled everything but the weather, which could not be controlled even by the best dictator who did not live in England. (*Laughter.*) Short of controlling the weather, they would do their best to make the visit of the Institute memorable. He would like on behalf of the Reception Committee to express in particular a real welcome to those visitors who came from foreign countries. (*Applause.*) Many present had enjoyed their hospitality abroad to an extent which they often felt they never adequately reciprocated. He could assure the foreign visitors that they were proud of their friendship, that they were very pleased to see them, and that they were always glad to be associated with them in the great interests

of their common industry. (*Applause.*) He knew of no other industry in which friendships were stronger and more international, thus making for goodwill throughout the world, than in the iron and steel industry. Long might that alliance last!

It was natural that the Iron and Steel Institute should come to Middlesbrough. The Institute had by now become an institution in the history of the iron and steel industry and of the world; it was an instrument for the continuing good of that industry, and without it there would be lacking to a large extent that development of intellectual acumen and of scientific attainment without which there could be no progress in the iron and steel industry, above all others. On behalf of the hosts, he wished all those who were attending the Meeting every success in their great work of helping the industry and thus facilitating the employment of more and more people, so adding to the comfort and wellbeing of many thousands throughout the world.

He must make some reference to the record of the Institute. Its first visit to Middlesbrough, in 1869, was memorable, because it was the birth of the Iron and Steel Institute. It was incorporated by Royal Charter in 1899, and the prefix " Royal " had never been more appropriately bestowed. It came to Middlesbrough again in 1885, and there were some present that day who had taken part in the visit of 1908, the last occasion on which the Institute had met there.

The presence of His Worship the Mayor, who had spoken so admirably earlier that morning, reminded him that in 1821 the population of Middlesbrough was 40. They must have been a very virile forty (*laughter*), because in 1831 the population had increased to 154, and a still more virile 154, because in 1908, at the time of the last visit of the Institute, the population was 104,000. To-day it was 140,000, and was still growing. (*Applause.*)

There was another set of figures which he would like to give. The great iron and steel industry in the main—not entirely, because in this matter the coal and other industries must be associated with it—had all but solved the problem of unemployment on Tees-side, and that without much help from the Government, apart from the Government's tariff policy, for which they were grateful. In 1932, the number of men on the unemployment register in Middlesbrough, Stockton and the Cleveland district was 44,641. In 1937 it had been reduced to 15,494, a decrease of 29,147. (*Applause.*) It was still decreasing, until to-day it had reached almost the very minimum of really employable people. In that great achievement, the iron and steel industry had borne the major part; and those engaged in it and in allied industries were very glad, looking beyond profits, to think that the revival of their indispensable industries had meant so much to tens of thousands of the most deserving men, women and children. (*Applause.*)

He would remind Members of the Institute that in Middlesbrough

they were within a few miles of the birthplace of Captain Cook, to whom this country owed Australia and New Zealand. They were also within a few miles of the first railway that ever ran, the Stockton and Darlington Railway, opened in 1825. They were in the very cradle of many of the great inventions and processes of modern industry, where they were thought out and carried into commercial realisation. This was not a matter of luck; it was due to the vitality, to the skill and to the courage of the people of the valley of the Tees, and he was one of those who believed that those virtues still remained, and that the district was destined to still greater progress in the future. (*Applause.*)

He would conclude by referring to the municipalities of the district and to the river. They had the municipal authorities, the river authorities, the railway and the industries all working together, as they ought to do and as they must do. They ought to make Tees-side what he believed it would become, a greater and greater waterway and home of industry. That would add to the comfort and wellbeing of the growing population. He hoped that when, in a few years' time, the Iron and Steel Institute returned to its home and its birthplace, Middlesbrough, Tees-side would be greater and more prosperous than at present, and he believed it would be better developed in every respect than it was now. (*Applause.*)

Sir WILLIAM LARKE, K.B.E. (Vice-President), who responded, said it was both a privilege and a responsibility to reply to Lord Greenwood's eloquent speech. He would like to say, on behalf of all those present, that if Lord Greenwood regarded the occupancy of his present position as one of the greatest achievements of his life, those engaged in the iron and steel industry for their part congratulated themselves that he had been induced to accept it, and they hoped most sincerely that he would long continue to hold it. (*Applause.*) Personally, he had first been privileged to meet Lord Greenwood when he held a high office under the Crown, an office the occupancy of which at that time required the highest physical and moral courage; anyone might well have shrunk from holding it. Lord Greenwood held it during a very troublesome period with great distinction, and personally he had felt great admiration for him then, an admiration which had been enhanced with the passage of time. The Members of the Institute would wish to thank Lord Greenwood for his good wishes. Before the luncheon, Lord Greenwood had remarked that it was appropriate that he should propose the toast, because he was not a Member of the Institute. He would not be allowed to get away with that indefinitely (*laughter*); he would very soon become a Member.

It was true to say that the success of the Iron and Steel Institute was synonymous with the success of the industry to which its Members belonged, and therefore, in drinking to its success, they were

really expressing their faith in the success of the industry of which they formed part, the success of which would be due to their own endeavours and their own faith in themselves and in their future.

He was one of those who had been privileged to visit Middlesbrough in 1908, and at that time the hope was expressed that some years later the Institute would come again and see the developments which had taken place in the interval. Since that time the industry everywhere had passed through the valley of depression, but now the Members of the Institute had come to Middlesbrough once more, and they knew that they were going to see some remarkable developments, developments which twenty-nine years ago no one, and least of all those who led the district at that time, could have anticipated. He would like to refer briefly to the remarkable progress which the district had made. Lord Greenwood had referred to it as the birthplace of many developments; personally, he would add that it had been also the cradle and the nursery of the modern iron and steel industry, and he hoped that it would continue to be so during the developments and improvements in technology on which the future of the industry depended. In the short time between 1932 and 1936, the production of pig iron in the district had increased by 140%, and the production of steel by no less than 150%. The Middlesbrough district, which in 1908 was second in its production to South Wales, had now taken the first place, with every probability of retaining it indefinitely.

There was one very important aspect of the activities of the district to which special reference might be made, and that was its record in the export trade. While the export trade of the iron and steel industry had increased since 1932 by some 2½%, exports through the port of Middlesbrough had increased by no less than 38%, showing that the district was doing a very large proportion of the total export trade in iron and steel of this country. The transit through the port of the raw materials of the industry and the export of its products was by far the highest of any port in the United Kingdom. The Members of the Institute had therefore every reason to visit Middlesbrough for their own instruction and inspiration as often as their Middlesbrough friends found it in their hearts to invite them.

At the last visit of the Institute to Middlesbrough, Sir Hugh Bell, dealing with the future, had said that far from there being any risk in the future to the iron trade, a far greater development lay before them than anything that had gone before. That was just as true to-day as it was when Sir Hugh Bell uttered it twenty-nine years ago, and perhaps more true, in view of the advances which had been made in technology as the result of scientific research. It had been said that in 1908 the industry was in a period of transition. Industry was always in a period of transition, thank God; if not, it would be moribund. He believed that to-day the industry was in a period of rapid transition of a more

far-reaching character than any within the memory of the oldest person present; and that was due to recent technical developments and to the results of research which the industry had undertaken during the last fifteen years.

He would like to conclude by saying a word as to the future. Lord Greenwood had mentioned the remarkable effect of the improvement in industry on the unemployment figures. Personally, he was one of those who believed that the major responsibility of industry was so to organise itself as to ensure the maximum employment of the people of this country. He thought that the iron and steel industry had shown not only an appreciation of the value of so doing, but that it had the technical ability and the industrial statesmanship so to order its policy as to secure the maximum employment for its people at any given time. The future of the industry was very largely in its own hands. It had sometimes been pertinently observed that the future of the industry was subject to conditions which were not within its own control. That was true to some extent, and was certainly true under present world conditions until the Government, in its wisdom, adopted its present fiscal policy; but, given the proper conditions, industrial statesmanship could do a very great deal to smooth out those waves of depression and boom which were frequently called the trade cycle and treated as though they were a law of nature or an act of God. He believed that the iron and steel industry had already shown that it had the capacity to do a great deal to stabilise conditions, and thus to maintain employment at its maximum volume. British industries must so order their policy, collectively and nationally, as to secure the maximum consuming power for their products, in order to maintain stability in employment and prosperity for the country.

It only remained for him, on behalf of the Members of the Institute, to thank the Reception Committee and the municipality for their cordial reception and for the programme which they had organised for the instruction, inspiration and entertainment of those attending the meeting, and to thank Lord Greenwood for his cordial and eloquent speech. (*Applause.*)

After the luncheon, parties of Members visited the following works, where they were also entertained to tea:

Acklam and Britannia Works of Dorman, Long & Co., Ltd.
Cargo Fleet Works of Cargo Fleet Iron Co., Ltd.
Cleveland Works of Dorman, Long & Co., Ltd.
Ormesby Works of Cochranes (Middlesbro') Foundry, Ltd.
Redcar Works of Dorman, Long & Co., Ltd.

During the afternoon the Ladies were taken to Whitby by motor coach. After tea at the Royal Hotel they made a short tour of the town and then drove to Mount Grace Priory.

In the evening Sir Maurice Bell, Bt., C.M.G. (Hon. Vice-President), entertained the Members and their Ladies at an evening party at Mount Grace Priory. The ruins of the Carthusian Monastery and the front of the house (which dates from 1654) were floodlit, and as darkness fell the buildings, outlined against the wooded background of the hillside, presented a scene of great beauty.

The visitors were received by Sir Maurice Bell, Bt., and Miss Johnson, in a marquee which had been erected in the cloisters, and supper was served in another huge marquee about 200 ft. long. The visitors left between 10.30 and 11.0 P.M. for their hotels. The efficiency of the transport arrangements in controlling the traffic in the main approach to the house—assisted by specially installed loud-speakers—met with general approval.

THURSDAY, SEPTEMBER 16TH.

Presentation of Papers.

The General Meeting was continued in the Cleveland Scientific and Technical Institute at 10 A.M., the President (Mr. Alfred Hutchinson) occupying the Chair.

The following Report and papers were then presented for discussion:

H. E. BLAYDEN, W. NOBLE and H. L. RILEY: "Some Experiments in a Small-Scale Cupola."

H. E. BLAYDEN, W. NOBLE and H. L. RILEY: "The Influence of Carbonising Conditions on Coke Properties. Part I.—Mechanical Pressure."

"FOAMED BLAST-FURNACE SLAG." By T. W. PARKER. (Being a Report of the Slag Tests Panel to the Blast-Furnace Committee of the Iron and Steel Industrial Research Council). (*Special Report No.* 19.)

The first two papers were discussed jointly.

The Meeting finished at about 12.30 P.M., and this concluded the Technical Sessions of the Meeting.

Visits and Entertainments for Members and Ladies.

Immediately the Technical Session was over Members were taken by motor buses to the following works:

Acklam and Britannia Works of Dorman, Long & Co., Ltd.
Ayrton Sheet Mills and Cleveland Wire Mills of Dorman, Long & Co., Ltd.
Cargo Fleet Works of Cargo Fleet Iron Co., Ltd.
Cleveland Works of Dorman, Long & Co., Ltd.
Redcar Works of Dorman, Long & Co., Ltd.
Works of Skinningrove Iron Co., Ltd.

The Members were entertained to luncheon and tea by the works visited.

The Ladies spent the whole day on an excursion to Rievaulx. Luncheon was taken in a marquee on the Terrace at Rievaulx at the invitation of the Ladies' Reception Committee, at which Miss Talbot presided. She welcomed the Ladies on behalf of her colleagues, and was thanked by Mrs. Hutchinson. After lunch a visit was paid to the ruins of Rievaulx Abbey, where Mrs. Frank Elgee, Curator of the Dorman Memorial Museum, gave an address on the history of the Abbey.

In the evening the Members and their Ladies were entertained at a ball and supper at the Town Hall, Middlesbrough, by invitation of the Reception Committee. The President and Mrs. Hutchinson received the guests. Dancing took place in the Main Hall, which had been specially decorated for the occasion, while supper was laid in the crypt. The dance was a great success and lasted until the early hours of the morning.

Friday, September 17th.

Visits and Entertainments for Members and Ladies.

The Members devoted Friday morning to visits to the following works :

Works of Ashmore, Benson, Pease & Co., Ltd., and of Head, Wrightson & Co., Ltd.
Clarence by-products rectification and distillation plant of Dorman, Long & Co., Ltd.
Works of Tees-side Bridge and Engineering Co., Ltd.
Works of Cleveland Bridge and Engineering Co., Ltd., and of the Whessoe Foundry and Engineering Co., Ltd.
Works of Darlington Forge, Ltd., and of the Darlington Rolling Mills, Ltd.
Billingham Works of Imperial Chemical Industries, Ltd.
Steel pipe works of the South Durham Steel and Iron Co., Ltd.

After the tours of inspection the visitors were entertained to lunch by the works concerned.

Meanwhile the Ladies made an excursion on the River Tees by invitation of the Tees Conservancy Commissioners; they were conveyed by motor buses to the Transporter Bridge, where they embarked on the Tees Commissioners' launch and were taken down the River to the Fifth Buoy. They returned to Middlesbrough in time for lunch, which was served by one of the caterers in the town on presentation of their badges.

In the afternoon the Members and Ladies were invited to a garden party at Solberge Hall by Mr. Benjamin Talbot, President of the Reception Committee. They were received by Mr. and Mrs. Benjamin Talbot, Miss Talbot and Mr. and Mrs. Chetwynd Talbot. The visitors were delighted to find that Mr. Talbot had recovered

sufficiently to be present in the marquee in which they were entertained to tea, although he asked his son Mr. Chetwynd Talbot to reply on his behalf to the speech in which the President expressed the thanks of the visitors to Mr. and Mrs. Talbot and their great regret that Mr. Talbot had not been able to come to the rest of the Meeting. Unfortunately the weather, which, with the exception of a few showers, had been remarkably good during the rest of the Meeting, was bad on Friday, but, nevertheless, the rain stopped towards the end of the garden party and the visitors were able to walk round the grounds and admire the beautiful views. Members and Ladies left at about 6.30 P.M., and were taken back in motor buses to their hotels. This brought to an end yet another very successful Autumn Meeting of the Institute in Middlesbrough.

SOME EXPERIMENTS IN A SMALL-SCALE CUPOLA.*

By H. E. BLAYDEN, W. NOBLE, and Professor H. L. RILEY
(Newcastle-upon-Tyne).

(Figs. 4 to 6 = Plate I.)

Summary.

The performances of some commercial and experimental-oven cokes and several carbons (electrode and retort carbon, petroleum coke, carbonised anthracite) have been compared under similar operating conditions in a small-scale experimental cupola with a shaft 9 in. in internal dia. and giving a melting rate of 220–250 lb. per hr. of iron at about 1330° C. The rate of combustion and of melting were markedly affected by the coke size and rate of air supply. Metal temperatures appeared to be more sensitive to variation in the coke size than to variation in the air blast above certain limits, which were probably fixed by the cupola dimensions and design. The use of highly graphitised carbons in the cupola tended to the production of increased metal temperatures. The cupola performances of cokes made in an experimental oven from two normal Durham coking slacks and the same slacks blended with up to 30% of coke fines were similar under similar operating conditions. Blending a normal Durham coking slack with 5 and 10% of crushed dry peat also had little effect on the cupola performances of the resultant experimental-oven cokes. The experiments suggest that differences in the performances of cokes under practical conditions are largely attributable to differences in the mechanical strength of the cokes.

Introduction.

Despite the increased knowledge of the nature of coke and the formulation of tests which permit the quantitative measurement of its properties, the factors which influence its behaviour in the blast-furnace and cupola are still obscure. The importance of mechanical strength, size grading and chemical composition is widely recognised, but there is no general agreement as to the influence of the porosity, nature of the ash, breeze blending, reactivity or combustibility, the extent of graphitisation, and certain other measurable properties.

Following on the pioneer work of the American Bureau of Mines[1,2] on the combustion of lump coke at high temperatures and at rates comparable with those in the blast-furnace hearth, other workers (*e.g.*, Haüsser and Bestehorn,[3] Midland Coke Research Committee[4] and others) have investigated the high-temperature combustion of lump coke on a reduced scale as a direct method of studying the factors operative in industrial practice. The present paper describes

* Received June 1, 1937.

experiments of a similar nature. Attempts have been made to imitate, on a reduced scale, the conditions prevailing in the full-scale cupola (*e.g.*, high temperature, the presence of molten slag and metal), and under these conditions to compare the performances of a variety of full-scale and experimental-oven cokes, and such different forms of carbon as electrode and retort carbon, carbonised anthracite, gas coke, petroleum coke, &c.

The experiments reported are largely of an exploratory nature, the ultimate object being to devise a method whereby the preparation of the coke and its utilisation for iron melting could be studied on an experimental scale, thus considerably reducing incidental costs and permitting improved control.

Preliminary experiments using a 6-in. shaft diameter cupola were only partially successful. The use of a 9-in. shaft diameter cupola, which is described below, proved a more feasible method of melting iron on a small scale under conditions approximating in many respects quite closely to large-scale practice.

Description of the Experimental Cupola.

The general dimensions and arrangement of the cupola are illustrated in Fig. 1. The cupola shaft, 9 in. in internal dia., was built of one-eighth circle fire-bricks (of 3-in. radial thickness) enclosed in a sheet-iron cylinder *A*, which was strengthened at each end with $1 \times \frac{1}{4}$-in. iron bands. The casing was secured to the hearth by bolted angle brackets. The hearth consisted of a ring of masonry *F* supported in a sheet-iron ring *G* and closed at its lower end by a solid, circular fire-brick *K*, 12 in. in dia. and 4 in. thick, supported by a metal prop. The well thus formed was 5 in. deep from the tuyere level and was lined with a fireclay-loam mixture so that the bottom sloped towards the tap-hole. One of the bricks forming the hearth wall could be inserted independently and was provided with a 1-in. dia. channel at the hearth level for tapping purposes. The air blast was provided by a $\frac{1}{2}$-h.p. blower capable of delivering up to 8000 cu. ft. of air per hr. at 10 in. W.G. pressure, and was introduced from a wind belt, 4 in. in dia., through the tuyeres ($1\frac{1}{2}$ in. internal dia. reduced to 1 in. dia. at the inner ends) inserted through the shaft walls 5 in. above the hearth. The blast volume and pressure were measured by an orifice gauge *N* and manometer *O* respectively. An automatic record of the blast volume was made to facilitate control. Cleaning and inspection holes *E*, normally closed by detachable screw caps, were arranged in the tuyeres. A slag tap-hole *H* was arranged in the shaft 1 in. below the tuyere level.

The cupola shaft and hearth could be relined or repaired when necessary by removing the bolts securing the two together, and tilting the shaft away from the hearth (*see* Fig. 4). The shaft could also be removed entirely. Provision was made for the observation of the shaft temperatures and the withdrawal of gas samples at different

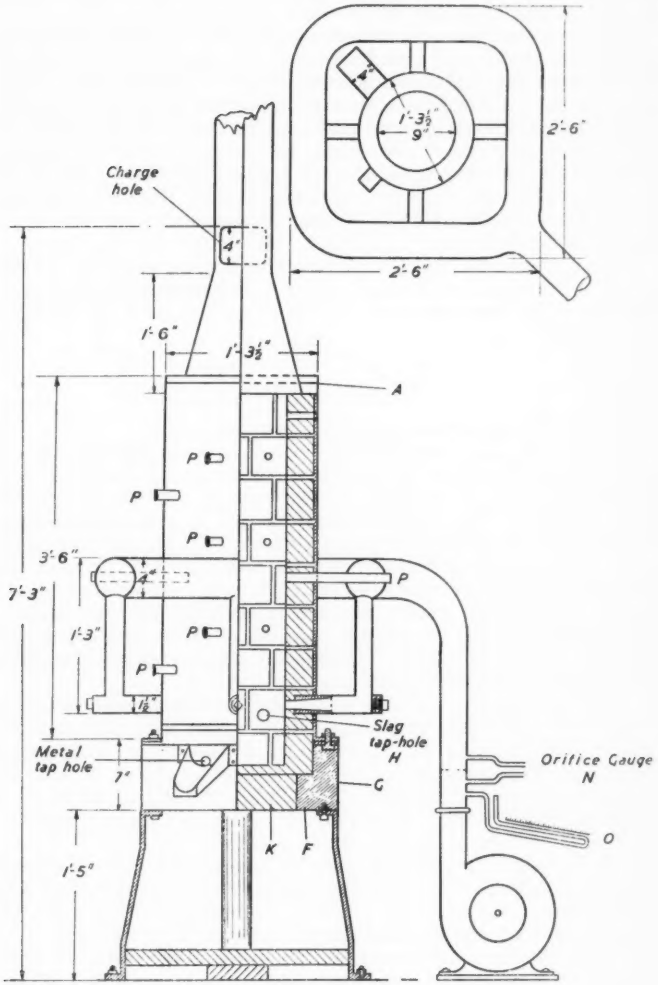
4"
1'-3½"
9"
2'-6"
2'-6"
Charge hole
4"
1'-6"
1'-3½"
A
P
P
P
P
3'-6"
4"
7'-3"
1'-3"
P
P
1½"
Slag tap-hole H
Metal tap hole
7"
G
Orifice Gauge N
O
K
F
1'-5"

FIG. 1.

heights in the shaft by arranging sight tubes *P* at appropriate heights around the shaft (*see* Fig. 1).

The test conditions were made as uniform as possible by using accurately graded coke and metal. All charges were weighed. The molten metal was run directly from the tap-hole into bar moulds (each 24 × 2 × 1 in.) made in a sand bed mounted on a movable trolley which could be run into position beneath the tap-hole. Provision was made for weighing the metal tapped in certain experiments. During each experiment the contents of the shaft were kept at an approximately constant height, level with the top of the shaft, by periodically adding coke, lime and metal in the appropriate ratios.

Metal temperatures were determined during tapping by two observers using standardised disappearing-filament pyrometers sighted on the metal stream at a point about 2 in. from the tap-hole.

Test Procedure.

The following general procedure was adopted.

(1) On the day immediately preceding each experiment, the cupola was relined to the standard dimensions (*see* Fig. 1) and thoroughly dried by lighting about 10 lb. of coke on the hearth, filling the shaft with 1½–2½ in. size coke (1–2 in. size in preliminary experiments) when the bottom layer was well alight, and leaving the coke to burn overnight under natural draught. On the next day the ash and unburnt coke were raked from the cupola through the space formed by the removal of the tapping brick, a fire was made in the hearth, and the shaft filled with coke, which was burnt with intermittent blast for 2½ hr. This procedure was adopted to obtain comparable initial test conditions.

(2) Incandescent coke of small size was then removed from the hearth until the remaining coke bed was of the appropriate height. The tapping brick was then fixed in position. The approximate height of bed required was determined by observations of the maximum height of erosion of the lining which had occurred in previous experiments. It was found to be approximately constant at a height of about 18 in. from the hearth.

(3) A weighed amount of the metal employed (bars of approximately 2 × 1 in. section, broken into pieces of approximately 3-in. length from the " once run " metal of a previous experiment) was introduced on to the coke bed and was followed by weighed amounts of the coke, lime and metal in the appropriate ratios until the shaft was filled level to the top. The cupola charge was allowed to " soak " for half an hour. The blast was turned on, adjusted to the required value, as shown by the orifice gauge, and maintained substantially constant at the desired rate.

(4) The time at which the metal first ran from the tap-hole was

observed, and at this point the tap-hole was closed with an asbestos-fireclay plug, and slag and metal were tapped intermittently as melting progressed. Charges were added to maintain an approximately constant height in the shaft. The time and temperature of the tappings were observed, temperatures being determined by two standardised pyrometers. The metal was run directly into bar moulds (24 × 2 × 1 in.) and the bars thus obtained were numbered

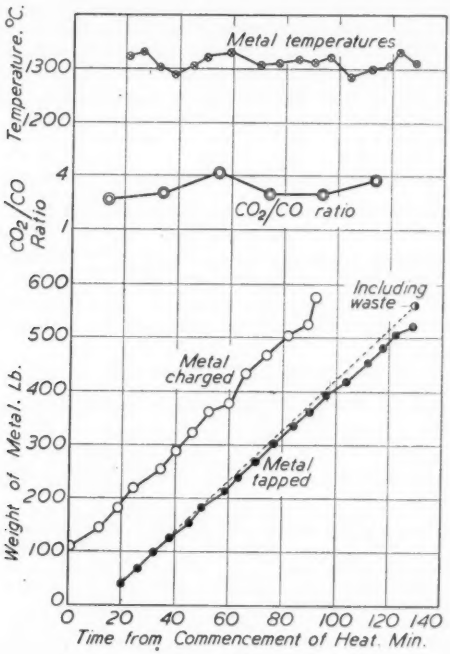

FIG. 2.

and were subsequently weighed to determine the weight of each tapping.

(5) After about 500–600 lb. of metal had been charged to the cupola, 6 lb. of coke and the appropriate amount of lime were charged, and melting and tapping continued until as much as possible of the molten metal had been removed from the cupola. The tapping brick was then removed and excess of slag raked from inside the hearth. The total amount of metal tapped, including waste, was determined.

(6) Several experiments were carried out employing coke-to-metal ratios initially of about 1 : 8 and increasing in successive experiments to the maximum ratio consistent with a metal temperature of the order of not less than 1260° C. Temperatures lower than this involved some risk of freezing of the metal in the hearth.

Using the procedure outlined, temperatures of the order of 1700° C. in the combustion zone and metal temperatures of about 1320–1360° C. could be obtained with certain cokes. Melting rates of about 220 lb. per hr. of iron at a temperature of about 1330° C. could be obtained with an average quality Durham coke ($1\frac{1}{2}$–$2\frac{1}{2}$ in. size) using a blast of 4000 cu. ft. per hr. and a metal-coke ratio of 6 : 1.

Fig. 2 shows a typical record of an experiment with a Durham coke. A photograph of the cupola in operation is reproduced in Fig. 5. Fig. 6 illustrates the type of bar castings made.

The Influence of Blast Volume and Coke Size.

A series of experiments employing the general procedure described, but with different rates of air blast (1800–3400 cu. ft. per. hr.), was made on two size gradings ($\frac{3}{4}$–$1\frac{1}{2}$ and $1\frac{1}{2}$–$2\frac{1}{2}$ in.) of a Durham beehive coke (357*A* and 357*C*, respectively). The characteristics of the coke are shown in Tables I., II., and III. The combustibility test results given in these Tables were obtained by a slightly modified

Table I.—*Proximate Analyses and Oxidation Rates.*

Sample No.	Description.	Ash. %.	Moisture. %.	Volatile Matter less Moisture. %.	Fixed Carbon. %.	Oxidation Rate. Mg. CO_2 per $2\frac{1}{2}$ hr.
339	Durham foundry coke.	6·2	0·4	0·8	92·6	204
342	" " "	8·4	0·3	0·7	90·6	214
357*A*	Durham beehive coke, $\frac{3}{4}$–$1\frac{1}{2}$ in. size.	5·7	0·9	0·8	92·6	176
357*B*	Durham beehive coke, 1–2 in. size.	5·9	1·0	1·0	92·1	184
357*C*	Durham beehive coke, $1\frac{1}{2}$–$2\frac{1}{2}$ in. size.	5·6	1·1	1·2	92·1	179
365	Durham horizontal retort gas coke.	8·6	0·5	0·9	90·0	143
375	Durham blend coke.	9·4	0·3	1·4	88·9	157
373	Retort carbon.	5·7	0·3	1·5	92·5	309
420	Durham furnace coke.	8·8	1·1	0·9	89·2	177
465	Electrode carbon.	4·2	0·1	0·6	95·1	589
466	" Roof carbon."	1·8	0·1	0·65	97·45	262
369	Petroleum coke.	2·0	1·6	7·9	88·5	417
478	Carbonised anthracite.	3·0	0·3	0·8	95·9	74
479	Retort carbon.	1·75	0·3	0·9	97·05	278
435–40	High-temperature experimental-oven coke.	8·75	1·9	2·8	86·55	154

TABLE II.—*Combustibility Test Results.*

Sample No.	Description.	Ignition Temp. ° C.	Max. Average Steady Temp. ° C.	Combustion Gas Analysis.			Carbon Consumption. G. per hr.
				CO_2. %.	CO. %.	CO_2/ CO.	
339	Durham foundry coke.	620	1170	14·2	9·8	1·45	45·6
342	,, ,, ,,	600	1180	14·3	10·3	1·39	45·8
357*A*	Durham beehive coke.	545	1185	14·3	10·3	1·39	45·8
357*B*	,, ,, ,,	530	1190	14·3	10·0	1·43	45·6
357*C*	,, ,, ,,	530	1180	14·4	10·0	1·44	45·6
365	Durham horizontal retort gas coke.	530	1175	13·7	11·1	1·23	46·7
375	Durham blend coke.	605	1205	13·7	11·2	1·22	46·8
373	Retort carbon.	...	...	...	...	...	...
420	Durham furnace coke.	520	1220	14·3	9·8	1·46	45·5
465	Electrode carbon.	550	1110	11·7	14·5	0·80	50·1
466	"Roof carbon."	630	1215	14·6	9·8	1·49	45·4
369	Petroleum coke.	...	...	...	...	...	...
478	Carbonised anthracite.	700	1195	14·7	9·8	1·50	45·3
479	Retort carbon.	610	1210	14·0	10·8	1·30	46·3
435–40	High-temperature experimental-oven coke.	555	1230	13·5	11·4	1·18	47·0

TABLE III.—*Critical Air Blast* (*C.A.B.*).

Sample No.	Description.	C.A.B. Cu. ft. per min.	Ignition Time. Sec.
339	Durham foundry coke.	0·086	231
342	,, ,, ,,	0·071	195
357*A*	Durham beehive coke, ¾–1½ in. size.	0·07 approx.	180 approx.
357*B*	Durham beehive coke, 1–2 in. size.		
357*C*	Durham beehive coke, 1½–2½ in. size.		
365	Horizontal retort gas coke.	0·074	210

form of the method described by Braunholtz, Nave and Briscoe,[5] and depended on the observation of the temperature of ignition and of steady combustion and the rate of carbon consumption (as deduced from analyses of the combustion gases) when 150 g. of the graded (5–10 I.M.M.) coke was ignited in a 2-in. dia. silica tube and burned in a constant air stream (0·2 cu. ft. per min.) under standardised conditions. The wet oxidation rates and critical air blasts (C.A.B.) were determined by the published methods.[6, 7]

The performances of the same coke in different size gradings but with the same air blast (2600 cu. ft. per hr.) were also compared using metal-coke ratios of 12 : 1. The results obtained are shown in Tables IV. and V. and Fig. 3.

TABLE IV.—*Effect of Variation in Blast.*

Metal-coke ratio = 12 : 1.

Blast. Cu. ft. per hr.	Tapping Rate. Lb. per hr.	Average Metal Temp. ° C.	Average CO_2/CO Ratio.	Consumption. Lb. per hr.		
				Calc.* Carbon.	Determined.†	
					Carbon.	Coke.
Coke No. 357C; 1½–2½ in. size.						
3400	295	1310	3·1	25·8	24·0	26
3000	280	1290	3·1	22·9	21·0	23
2600	240	1290	3·4	19·6	18·5	20
2200	208	1285	3·4	16·5	16·5	18
1800	171	1220	4·4	13·2	13·0	14
Coke No. 357A; ¾–1½ in. size.						
3100	336	1260	1·9	24·7	24·5	27
2600	289	1265	2·0	20·8	22·5	24

* From gas analyses. † From charging rates.

TABLE V.—*The Effect of Coke Size.*

Metal-coke ratio = 12 : 1. Blast = 2600 cu. ft. per hr.

Coke.		Tapping Rate. Lb. per hr.	Average Metal Temp. ° C.	Average CO_2/CO Ratio.	Consumption. Lb. per hr.		
No.	Size. In.				Calc.* Carbon.	Determined.†	
						Carbon.	Coke.
357A	¾–1½	289	1265	1·9	20·8	22·5	24
357B	1 –2	260	1280	3·3	19·5	20·0	22
357C	1½–2½	240	1290	3·4	19·5	18·5	20

* From gas analyses. † From charging rate.

It is evident from Table IV. and Fig. 3 that an increase in the blast supplied to the cupola increased proportionately the rates of carbon or coke consumption and the rates of melting with both 1½–2½ and ¾–1½ in. sizes of the beehive coke No. 357. The average temperature of the metal was not, however, increased proportionately. An increase of the blast from 1800 to 2200 cu. ft. per hr. produced a marked increase in temperature, but further blast increases had only slight effects on the metal temperature (Fig. 3). It is probable that the true relation between metal temperature and amount of blast or rate of coke consumption is of a kind illustrated by the curve shown as a dotted line at the top of Fig. 3.

A decrease in the size of coke charged increased the rates of coke

consumption and of melting, but reduced the metal temperatures and the CO_2/CO ratio of the shaft gases (Table V.).

In the experiments described, the charge ratios were fixed, and the rates of coke consumption and of melting were thus interdependent. The increase in the rate of melting due to the use of small size coke or high blast rate was therefore a result of the increased

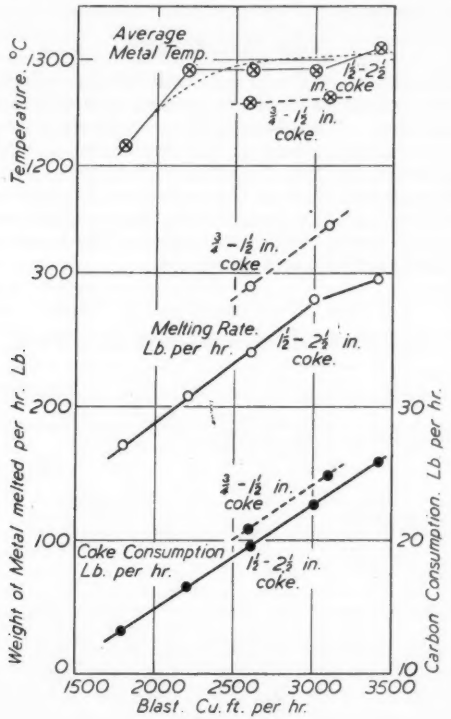

FIG. 3.

rate of coke consumption, which involved a correspondingly increased throughput of metal.

These results are in keeping with those obtained by Haüsser and Bestehorn [3] and others [4] in experiments made on graded coke in the absence of slag and iron. It follows that, in agreement with practice in full-scale furnaces, the use of high blast rates and large coke tends to improved melting efficiency, as assessed by metal temperatures and rates of melting. The relatively low metal (or

coke-bed) temperatures resulting from the use of small coke (Table V.) were possibly due to the increased endothermic production of carbon monoxide, as indicated by the shaft gas analysis. The tendency to approach an upper limit of temperature as the blast rate was increased (Fig. 3) suggests also that, within certain temperature limits determined by the cupola dimensions and design, metal temperatures are more sensitive to variation in coke size than to variation in blast rate.

Comparative Tests.

(*a*) *A Comparison of Four Commercial Cokes.*—Table VI. gives the results of comparative experiments on four different cokes, all of 1–2 in. grading. Coke No. 357*B* was a Durham beehive coke, Nos. 339 and 342 were Durham foundry cokes, and No. 365 was a horizontal retort Durham gas coke (*cf.* Tables I.–III.). The ratio of metal to coke employed in the respective experiments was the optimum ratio giving maximum melting rates consistent with metal temperatures of about 1260° C. or higher. The rate of air supply was maintained at 2600 cu. ft. per hr.

Table VI.—*Comparison of Cokes.*

Blast = 2600 cu. ft. per hr. Coke size = 1–2 in.

Coke No.	Description.	Metal-Coke Ratio.	Tapping Rate. Lb. per hr.	Average Metal Temp. ° C.	Average CO_2/CO Ratio.	Consumption. Lb. per hr.		
						Calc.* Carbon.	Determined.†	
							Carbon.	Coke.
357*B*	Durham beehive coke.	12	260	1280	3·3	19·5	20·0	22
339	Durham foundry coke.	12	227	1260	2·1	20·7	18·5	20
342	,, ,, ,,	10	210	1280	...	20·6	18·0	20
365	Durham horizontal retort gas coke.	12	250	1275	3·4	19·3	19·0	21

* From gas analyses. † From charging rate.

The results collected in Table VI. show that, although the performances of the several cokes in the experimental cupola were similar, the beehive coke (No. 357*B*) gave the highest melting rate and metal temperatures. The horizontal retort gas coke (No. 365) was almost as efficient as the beehive coke under the test conditions, and although the patent cokes Nos. 339 and 342 gave very similar performances, the latter coke tended to be less efficient, as shown by the lower optimum ratio of metal to coke in the charge. A separate experiment, in which the metal-coke ratio was fixed at 11 : 1, tended to confirm this result. In this experiment coke No. 342 was charged for the first half of the experiment (1½ hr.) and coke No. 339 was substituted for it in subsequent charges. Under these conditions the melting rate remained approximately constant throughout the

whole experiment, but the metal temperature, which had fallen to 1250° C. before the substitution of No. 339 for No. 342, was increased to about 1280° C. by the use of coke No. 339.

(*b*) *A Comparison of Different Carbons.*—The above experiments indicate that, although it is possible to detect differences in the performances of cokes under very similar operating conditions, these differences are, on the whole, small.

There is a widespread belief that the combustion of cokes of low volatile content (*e.g.*, highly graphitised materials, *cf.* Balfour, Riley and Robinson[8]) leads to the production of high temperatures and efficient working in a cupola. An attempt was therefore made to assess the maximum differences in cupola performance which could be observed by the use of widely different types of carbon. The method of comparison employed in the foregoing tests, *viz.*, determination of the metal temperature and melting rate for the optimum metal-coke ratio, whilst perhaps giving the clearest differentiation in coke efficiencies, proved both laborious and expensive. In some of the tests the available amounts of material were relatively small, and it was necessary to effect some simplification of the tests by using a fixed metal-coke ratio. The following comparisons were made on this basis.

Table VII. summarises the results of comparative tests on two

TABLE VII.—*Comparison of Different Carbons.*

Coke grading = 1½–2½ in. Metal-coke ratio = 6 : 1.
Blast = 4000 cu. ft. per hr.

Sample No.	Description.	Mean Metal Temp. ° C.	Melting Rate. Lb. per hr.	Bulk Density, 1½–2½ in. Coke. Lb. per cu. ft.
375	Durham blend coke.	1312	223	
		1300	222	...
	Mean	1306	223	
...	Coke 375 + 50% retort carbon (No. 373).	1340	241	...
420	Durham furnace coke.	1340	206	
		1335	212	23·3
	Mean	1337	209	
465	Electrode carbon.	1370	233	
		1350	233	44·5
	Mean	1360	233	
466	"Roof carbon."	1390	227	30·0
369	Petroleum coke.	1300*	210	...

* Maximum temperature 1330° C. after 1¾ hr., falling continuously to 1270° C.

furnace cokes, electrode carbon, retort carbon (from the walls and roof of a modern high-temperature oven), and a sample of petroleum coke. The latter material, which contained small amounts of soda from the original distillation process, represented an extreme type of material. Its volatile matter content and oxidation rate were relatively high, as could be expected from its origin and preparation (distillation of petroleum pitch).

The electrode carbon, which was kindly supplied for these tests by Messrs. Hadfields, Ltd., Sheffield, was probably prepared by the high-temperature carbonisation of a compressed mixture of powdered anthracite and binding agents such as pitch and/or coking coals. In the cupola tests the metal-coke ratio was fixed at 6 : 1 and the blast volume at 4000 cu. ft. per hr. Variations in blast pressure throughout the series of experiments were negligibly small. The cokes or carbons were graded to 1½–2½ in. size and the general procedure of the tests was as described above.

The results of further comparative tests made on 1–1½ in. material are shown in Table VIII.

TABLE VIII.—*Comparison of Different Carbons.*

Blast = 4000 cu ft. per hr. Coke grading = 1–1½ in.
Metal-coke ratio = 6 : 1.

Sample No.	Description.	Mean Metal Temp. ° C.	Melting Rate. Lb. per hr.
478	Carbonised anthracite.	1330	219
		1330	214
	Mean	1330	216
465	Electrode carbon.	1305	241
479	Retort carbon.	1316	231
		1325	235
	Mean	1320	233
435–40	High-temperature experimental-oven coke.	1305	230
		1315	230
	Mean	1310	230

The use of 1–1½ in. graded material was necessitated by the difficulty of obtaining larger sizes of the carbonised anthracite, which broke down considerably during preparation by carbonising a South Wales anthracite for 12 hr. in a chamber oven at 1300–1350° C.*

The results of laboratory tests on the respective carbons are collected in Tables I.–III. and IX.

* The authors are indebted to the Fuel Research Station, Greenwich, for the preparation of this material.

TABLE IX.—*Bulk Densities, Apparent Specific Gravities and Porosities.*

Sample No.	Apparent Specific Gravity.	Apparent Porosity. %.	Bulk Density. Lb. per cu. ft.
478	1·61	6·0	54·1
465	1·53	20·4	46·6
479	1·16	37·2	30·5
435–40	0·89	47·1	27·5

Table VII. clearly shows that the use of retort carbon or electrode carbon leads to the production of increased metal temperatures and, under the experimental conditions employed, increased rates of melting. An examination of the ash contents of the carbons indicates that the differences cannot be attributed entirely to differences in fixed carbon content. Both these materials may be considered to consist largely of highly graphitised carbon, as is suggested by their relatively large wet oxidation rates (Table I.). The high wet oxidation rate of the petroleum coke was shown in separate experiments to be due to incomplete carbonisation and its relatively large volatile matter content. The results obtained thus tend to support the view that a high degree of graphitisation is a desirable property of cupola cokes (*cf.* Riley [9]).

The metal temperatures obtained by the use of 1–1½ in. gradings of electrode carbon, retort carbon and high-temperature coke were, however, very similar (Table VIII.), although the average metal temperature given by retort carbon was slightly greater than that given by the other two carbons. The sample of carbonised anthracite, although possessing a small wet oxidation rate (Table I.), gave the highest average metal temperature and the lowest melting rate. The results of laboratory tests on the carbons employed (Table II.) suggest that the high average metal temperature and relatively low melting rate given by the carbonised anthracite were connected with the relatively low rate of carbon monoxide production and associated reduced rate of carbon consumption observed. A converse phenomenon might be suggested to explain the low metal temperature and high melting rate of the electrode carbon, which gave an unexpectedly low CO_2/CO ratio and high rate of carbon consumption in laboratory tests (*cf.* Table II.). There was, indeed, an approximately general parallelism between the CO_2/CO ratios and carbon consumptions in the laboratory tests and the results of the cupola tests.

The apparent densities, porosities and bulk densities of the materials examined in the foregoing tests were markedly different (Table IX.). The possible influence of these factors upon the results of the cupola tests makes it difficult to draw any definite conclusions, particularly in view of the limited number of tests made.

The commercial importance of a knowledge of the influence of the extent of graphitisation in the combustion of carbon prompted a

further comparison on a technical scale. For this purpose, full-length pieces of a commercial coke (carbonised for 29½ hr. in a 20-in. oven from a Durham coking mixture) were broken into halves to obtain bulk samples of coke from nearest the oven wall (outer ends, sample No. 316) and from the middle of the oven (inner ends, sample No. 317). In this way large samples (about 3 tons each) of coke greater than about 3-in. size were obtained, with the same ash content, from the same coal, and differing only in the extent of carbonisation and presumably also in their extent of graphitisation. Difficulties arising from possibilities of variation in the original coal, &c., which would be met with by carbonising separate batches of coals, were therefore eliminated. The coke thus obtained was examined, in collaboration with the British Cast Iron Research Association, in a full-scale cupola (expanded well hearth 51 in. in dia.; minimum diameter at tuyeres 30 in., flared out to approximately 60-in. shaft) using uniform metal charges and fixed charge ratios. Table X. shows the results of laboratory tests on average samples of the two batches of coke and Table XI. summarises the data of the large-scale cupola trials.

TABLE X.—*Comparison of the Properties of Inner and Outer Portions of Half-Oven-Width Pieces.*

	Outer Portions, Coke No. 316.	Inner Portions, Coke No. 317.
Ash. %	6·4	6·4
Volatile matter, less moisture. %	1·3	1·9
Moisture. %	0·8	1·3
Sulphur :		
Total. %	0·70	0·61
Fixed. %	0·104	0·108
Oxidation rate, mg. CO_2 per 2½ hr.	218	178
Shatter index. Percentage on 2 in./ percentage on 1½ in.	88/95	91/95
Apparent specific gravity	0·92	0·86
Apparent porosity. %	44·0	52·9
Combustibility test :		
Ignition temp. ° C.	560	490
Max. steady combustion temperature. ° C.	1190	1160
CO_2/CO ratio	1·41	1·43
Carbon consumption. G. per hr.	45·75	45·6

TABLE XI.—*Large-Scale Cupola Trials.*

	Outer Portions, Coke No. 316.	Inner Portions, Coke No. 317.
Mean metal temperature. ° C.	1295	1290
Mean blast volume. Cu. ft. per min.	3804	3701
Mean blast pressure. In. water gauge	15·0	17·0
Melting rate. Tons per hr.	8·1	7·7

It is evident from these Tables that despite the lower shatter index of the coke from the outer portions of the half-width pieces and the lower blast pressure when using this coke in the cupola, it gave a slightly better performance, as judged by both metal temperatures and melting rates. This is of course an isolated result, but it seems reasonable to regard it tentatively as contributory evidence favouring the conclusion that, other properties being the same, a high degree of graphitisation is a desirable property in a metallurgical coke.

(*c*) *The Relative Efficiencies of Blend Cokes.*—The admixture of small proportions of finely crushed coke with certain coking slacks is known to effect some improvement in the mechanical properties (*e.g.*, shatter index) of the coke produced from the slack. In certain localities, blending with coke fines is regularly practised with success for the production of blast-furnace coke, and its advantageous effects in certain cases are beyond doubt (*cf.*, for example, T. Biddulph Smith [10, 11]).

TABLE XII.—*Results of Laboratory Tests. Blend Series* A.

Durham coking slack *C*402 : Ash 5·6%, volatile matter (ash-free, dry) 34·8%.
Coke fines : Ash 8·4%, volatile matter 2·2%, fixed carbon 88·2%.

	Experimental-Oven Cokes.				Full-Scale Oven Cokes.	
Coke No. :	402	403	404	405	378	377
Percentage of coke fines :	0	5	10	20	0	5
Shatter test :						
Index. Percentage on 2 in./percentage on 1½ in.	74/88	74/89	86/92	86/92	74/90	76/91
Percentage on ½ in.	97·8	97·5	97·2	96·0	...	...
Apparent specific gravity	0·83	0·85	0·87	0·93	1·02	1·00
Apparent porosity. %	48·9	51·0	52·9	51·6	38·0	43·4
Proximate analysis :						
Ash. %	7·4	7·6	7·5	7·3	9·5	9·2
Moisture. %	1·8	0·8	1·6	1·6	0·3	0·4
Volatile matter, less moisture. %	1·8	1·4	2·3	2·0	1·3	1·3
Fixed carbon. %	89·0	90·2	88·6	89·1	88·9	89·1
Oxidation rate, mg. CO_2 per 2½ hr.	109	142	134	160	162	158
Combustibility test :						
Ignition temp. ° C.	605	570	535	505	630	610
Max. steady temp. ° C.	1210	1235	1255	1245	1210	1190
CO_2/CO ratio	1·32	1·18	1·10	0·95	1·16	1·18
Carbon consumption. G. per hr.	46·2	47·1	47·6	48·7	47·2	47·1

Evidence collected by the Northern Coke Research Committee indicates clearly that the effect of blending the parent coking slack with coke fines is different for different coals. This aspect of blending with coke fines has not been sufficiently emphasised in the past and explains the adverse effects of such blending sometimes observed.[12]

Blending a coking slack with finely crushed coke tends in general to increase the shatter index of the coke (*cf.* Table XII.). In some cases, however, the increase in shatter index is accompanied by an increase in the abradability.[12] In the experimental cupola tests described in the foregoing pages the influence of fissuring (which chiefly determines the shatter index) is largely eliminated by reduction of the coke to $1\frac{1}{2}$–$2\frac{1}{2}$ in. size. Moreover, the influence of the abradability of the coke on the results of the cupola tests is small because of the relatively small burden of the cupola. Comparison of the performances of normal and blended cokes in the cupola therefore offered a useful method of assessing the influence of blending upon the combustible properties of coke in the almost complete absence of disturbing factors arising from breakage by impact or abrasion. Information on this aspect of blending is almost completely lacking, and the following experiments were undertaken to provide data on this point.

TABLE XIII.—*Results of Laboratory Tests. Blend Series* B.

Durham coking slack *C*435 : Ash 7·8%, volatile matter (ash-free, dry) 29·7%.
Coke fines : Ash 14·8%, volatile matter 2·6%, fixed carbon 81·2%.

Coke No. : / Percentage of coke fines :	435 / 0	436 / 5	437 / 10	438 / 15	439 / 20	440 / 30
Shatter test :						
Index. Percentage on 2 in./percentage on $1\frac{1}{2}$ in. . . .	80/90	84/91	88/92	90/93	91/94	90/93
Percentage on $\frac{1}{4}$ in. .	96·9	96·8	96·3	96·7	96·4	96·3
Apparent specific gravity . . .	0·85	0·85	0·89	0·90	0·91	0·94
Apparent porosity. %	50·3	48·8	48·7	45·6	44·2	44·9
Proximate analysis :						
Ash. % . .	9·8	9·6	9·7	10·0	10·6	10·4
Moisture. % . .	0·9	2·0	1·8	2·2	2·1	2·2
Volatile matter, less moisture. % .	1·6	3·1	1·9	3·1	2·9	3·5
Fixed carbon. % .	87·7	85·3	86·6	84·7	84·4	83·9
Oxidation rate, mg. CO_2 per $2\frac{1}{2}$ hr. . .	182	140	164	151	162	162
Combustibility test :						
Ignition temp. °C. .	615	540	565	530	500	495
Max. steady temp. °C.	1220	1240	1235	1245	1190	1200
CO_2/CO ratio . .	1·56	1·47	1·35	1·26	1·28	1·07
Carbon consumption. G. per hr. . .	45·1	45·4	46·1	46·2	46·4	47·8

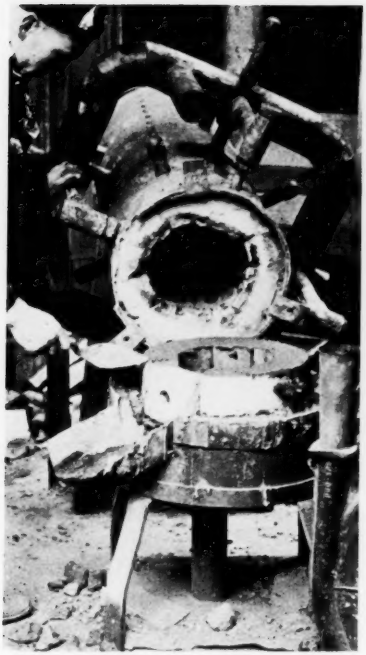

FIG. 4.—Experimental Cupola arranged for Relining.

FIG. 5.—Tapping Metal.

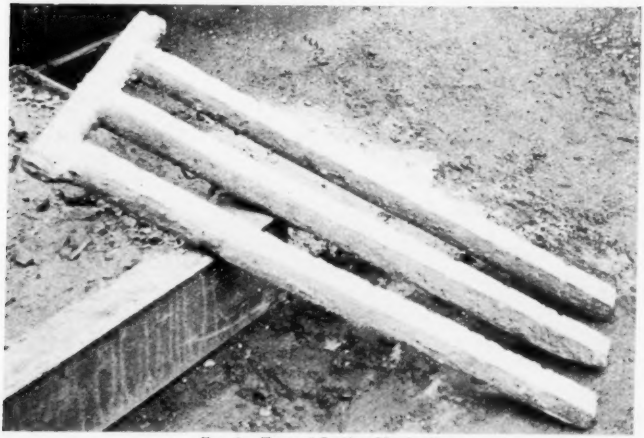

FIG. 6.—Type of Casting Obtained.

[*Blayden, Noble and Riley.*
[*To face p.* 40 P.

The cokes were prepared from two Durham coking slacks carbonised alone and after thoroughly mixing with up to 20 or 30% of coke fines. Carbonisation was effected at about 900° C. in a top-charged experimental oven, 8 ft. high, 3 ft. 6 in. long and 18 in. in mean width, holding a charge of about 17 cwt. Particulars of the parent mixtures and results of laboratory tests on the cokes are collected in Tables XII. and XIII.

Experimental cupola tests were made in duplicate on $1\frac{1}{2}$–$2\frac{1}{2}$ in. sizes of these cokes, using a constant metal-coke ratio of 6 : 1 and the general test procedure described. Full-scale cokes made from one of the coking slacks and from a blend of the slack containing 5% of coke fines were also examined. The results obtained are collected in Table XIV.

TABLE XIV.—*Collected Results. Cupola Tests on Breeze Blends.*

Coke No.	Description.	Mean Metal Temp. ° C.*	Melting Rate. Lb. per hr.*
402	100% coal *A*.	1290	204
403	95% coal *A* + 5% fines.	1300	195
404	90% coal *A* + 10% fines.	1320	196
405	80% coal *A* + 20% fines.	1305	218
378	Full-scale coke corresponding to No. 402.	1323	222
377	Full-scale coke corresponding to No. 403.	1312	217
435	Normal mixture.	1318	212
436	Normal mixture + 5% fines.	1313	213
437	Normal mixture + 10% fines.	1327	212
438	Normal mixture + 15% fines.	1323	214
439	Normal mixture + 20% fines.	1322	211
440	Normal mixture + 30% fines.	1304	222

* Mean of duplicate tests.

The influence of blending with coke fines on the physical properties of the coke is well illustrated in Tables XII. and XIII. In general, the shatter index was increased by blending, and the apparent specific gravity progressively increased with increasing content of admixed fines. With one series (series *A*), the blend containing 20% of coke fines (coke No. 405) tended to be more abradable, as indicated by the lower $\frac{1}{2}$-in. shatter index. The influence of blending on the porosity of the cokes was also different for the two series of blends examined.

Laboratory combustibility tests (Tables XII. and XIII.) on the various cokes indicated definite increases in the rates of combustion, associated with increased rates of production of carbon monoxide, with increasing content of admixed coke fines. Although, in general, blending with coke fines tended to decrease the ignition

temperature and to increase the temperature of steady combustion in these tests, there appeared to be a tendency for mixtures containing 20 and 30% of coke fines to give relatively low ignition temperatures and low steady combustion temperatures.

Despite these and other differences in the results of laboratory tests on the experimental-oven cokes, no marked differences in their behaviour in the experimental cupola were observed (Table XIV.). It is perhaps noteworthy that the low metal temperatures and high melting rates of coke No. 440 (from mixtures containing 30% of coke fines) were in agreement with the results of the laboratory combustibility tests on this coke. Coke No. 405 (20% of coke fines) behaved somewhat similarly. The relative order of the metal temperatures and melting rates of the full-scale cokes (Nos. 378 and 377, Table XII.) was also reflected in the results of the combustibility test. In this connection it may be stated that the slightly lower metal temperature and melting rate of the full-scale coke made from the mixture with 5% of fines was in keeping with the reported slightly inferior performance of this coke in the blast-furnace.

A survey of the results of the experimental cupola tests (Table XIV.) suggests that, under similar conditions of size grading and rate of air supply, corresponding normal and breeze-blended cokes give substantially the same performance at the high temperatures prevailing in the cupola (about 1650° C. in the combustion zone in the experiments described). It is, of course, possible that this result may be traced to a general similarity of the cokes arising from slight under-carbonisation in the experimental oven, a factor which is very difficult to eliminate in small-scale carbonisation processes. The general implication is, however, that the influence upon the combustible properties of coke of blending with coke fines is probably small, and that differences of performance observed under practical conditions are chiefly attributable to the predominating influence of differences in mechanical strength and the consequent production (by impact, abrasion or other factors) of variable amounts of small coke. The marked influence of the latter factor is shown by the experiments on size grading described above. These conclusions, although only strictly applicable to coal blends similar to those examined, are in keeping with the frequently expressed opinions of blast-furnace operators.

Table XV. gives the results of experimental cupola tests made on cokes from a Durham coking slack and the same slack containing 5 and 10% of finely crushed peat respectively (cokes Nos. 420, 421 and 422). The cokes were prepared in the experimental oven described above. The shatter indices of the three cokes were practically the same, but differences in the results of laboratory tests (Table XVI.) on the respective cokes could be detected. These differences were not, however, as great as might be expected with blends containing such an extreme type of material as peat. Despite the observed difference in the cokes, the results of the experimental

cupola tests were very similar, and, indeed, were not greatly different from those obtained in the foregoing experiments.

TABLE XV.—*Results of Cupola Tests.*

Coke No.	Description.	Mean Metal Temp. ° C.	Melting Rate. Lb. per hr.	Bulk Density, 1½–2½ in. Coke. Lb. per cu. ft.
420	Durham furnace coke.	1340	206	23·3
		1335	212	
	Mean	1337	209	
421	Coal used for No. 420 + 5% peat.	1315	203	24·3
		1325	205	
	Mean	1320	204	
422	Coal used for No. 420 + 10% peat.	1330	223	24·1
		1325	214	
	Mean	1327	218	

TABLE XVI.—*Results of Laboratory Tests. Blend Series* C.

Durham coking slack *C*420 : Ash 6·8%, volatile matter (ash-free, dry) 30·1%.
Peat *C*412 : Ash 6·0%, volatile matter 63·8%.

Coke No. : / Percentage of peat :	420 / 0	421 / 5	422 / 10
Shatter test :			
Index. Percentage on 2 in./percentage on 1½ in.	80/90	79/89	78/89
Percentage on ½ in.	96·9	97·0	97·0
Apparent specific gravity	0·82	0·84	0·82
Apparent porosity. %	48·1	48·1	53·0
Proximate analysis :			
Ash. %	8·8	8·1	8·0
Moisture. %	1·1	1·2	1·8
Volatile matter, less moisture. %	0·9	1·9	2·5
Fixed carbon. %	89·2	88·8	87·7
Oxidation rate, mg. CO_2 per 2½ hr.	177	173	170
Combustibility test :			
Ignition temp. ° C.	520	455	470
Max. steady temp. ° C.	1220	1200	1180
CO_2/CO ratio	1·46	1·37	1·17
Carbon consumption. G. per hr.	45·5	45·95	47·1

GENERAL CONCLUSIONS.

The experiments described in the foregoing pages demonstrate the feasibility of melting iron on a small scale under controlled

conditions, and, irrespective of the applications to research, suggest interesting possibilities of the small-scale cupola as a standby for occasional small castings.

The range of variation of either metal temperatures or melting rates obtainable with average metallurgical cokes was relatively small. It is doubtful, therefore, whether the present design of the cupola permits a clear differentiation of any but extreme varieties of cokes and carbons. Slightly better differentiation might have been obtained by the use of a higher shaft, a modification which was not practicable.

The coke size and rate of air blast markedly influenced both the rates of combustion and melting. Metal temperatures appeared to be more sensitive to variation in the coke size than to variation in the air blast above certain limits, which were probably determined by the cupola dimensions and design. The coke size and rate of air supply, *i.e.*, the area and time of contact of the coke and air, thus appeared to be predominating factors during combustion. This observation, considered in conjunction with the general similarity of the performances of the cokes examined, suggests that differences in coke performances under practical conditions are largely attributable to the production of variable amounts of small coke in the furnace, due to differences in mechanical strength of the cokes.

The general inference from the results described thus tends to support the view that the hearth temperatures obtained in cupola operation, and probably also in blast-furnace practice, are less affected by differences in coke reactivity than by differences in mechanical strength of the coke. The higher hearth temperatures observed with highly graphitised materials (Table VII.) suggest, however, that differences in reactivity might become effective under certain conditions.

The above experiments were carried out in the laboratory of the Northern Coke Research Committee, Armstrong College, Newcastle-upon-Tyne, and grateful acknowledgement is made to the Committee for permission to utilise the data obtained.

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[This paper was discussed jointly with the following one by Blayden, Noble and Riley.]

THE INFLUENCE OF CARBONISING CONDITIONS ON COKE PROPERTIES.*

PART I.—MECHANICAL PRESSURE.

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Summary.

Two Northumberland " non-coking " coals have been carbonised under mechanical pressures ranging from 0·2 to 20 lb. per sq. in., and the effect of coal size has been studied with one of these coals. The relative strengths of the cokes prepared have been measured by a new apparatus which has been devised for this purpose. The indices obtained show remarkably close correlation with other physical and chemical properties. Increase in carbonisation pressure produced a pronounced increase in the strength of the resultant coke. In certain cases the strength index of the coke was raised from zero to that given by metallurgical cokes. The effect of pressure on coke strength is shown to depend on the coal size and grading. The coke strength decreased with decrease in size at low pressures and increased with decrease in size at higher pressures, with the coal examined. The cause of the observed influence of pressure is discussed.

It is generally considered that the mechanical pressures developed in the plastic zone during the coking of coal play an important part in the agglomeration or binding phenomena which are characteristic features of coke formation. Several investigators have studied the magnitude of the pressures developed, chiefly on the basis of laboratory experiments. Mott,[1] for example, found that pressures of about 800 lb. per sq. in. were necessary to inhibit the swelling of a uniformly heated column of particles of a coking coal. Other workers (Damm,[2] Pieters,[3] Hofmeister,[4] Lambris,[5] Baum and Heuser [6]), employing unilateral methods of heating such as obtain in the coke-oven, have observed lower pressures ranging from about 2 to about 68 lb. per sq. in., depending on the nature of the coal, the rate of heating and certain other factors. According to Koppers and Jenkner,[7] the pressure exerted on the oven walls by the expansion of the coal charge is considerably less than that observed in small-scale tests (*cf.* also Ryan [8] and Foxwell [9]), and is markedly influenced by the bulk density and moisture content of the coal charge, by the shrinkage of the coke formed and by the characteristics of the oven.

Gauger, Taylor and Ulmen [10] have studied the influence of applied pressure on the carbonisation of lignites, which normally yielded a powdery char in laboratory carbonisations at normal

* Received July 9, 1937.

pressure. By briquetting the powdered lignite under pressure and carbonising at 600° C. under mechanical pressures of 650–1900 lb. per sq. in. a compact " coke " was obtained. Within certain limits, the effects of pressure and temperature were apparently complementary in inducing coking of both lignites and mixtures of lignite char with small amounts of a coking coal. The more extensive work of Swietoslawski, Roga and Chorazy,[11] on the briquetting of coal by compression at temperatures within the plastic range, also illustrates the important part played by pressure during coking on the strength of the residue. The products obtained by them represented, of course, only the initial stages of coke formation. The increased density and strength of the residue (as assessed by " tumbler " and shatter tests) consequent on the improved binding effects at high pressures, were, however, clearly indicated.

The cracking of the vapours and gases entrapped under high pressure in the plastic coal during coking may also markedly influence the properties of the coke produced. Fischer, Bahr and Sustmann[12] have shown, for example, that dense cokes could be obtained from coals, normally considered to be non-coking, when the carbonisation was effected under gas pressures of about 50 atm. Under similar pressure conditions the coke from coking coals increased markedly in density. The observed improvement in the quality of the coke was associated with a decrease in the tar yield, owing to cracking which occurred during carbonisation at the high gas pressure.

Although the general effects of pressure, both in laboratory carbonisation and in practice, are widely recognised, little quantitative information is available in respect of the influence of this factor on the mechanical strength of coke. This is perhaps largely due to the difficulty of direct investigation under practical conditions and to the lack of an adequate means of assessing the mechanical strength of laboratory-prepared cokes. This difficulty appears to be surmounted by a method which is described in the present paper and which enables an examination of the influence of carbonising conditions on coke properties to be made in greater detail than has hitherto been possible.

The method has been applied to the carbonisation of two poorly coking coals. The data obtained, whilst being largely of a preliminary character, have an obvious bearing on the utilisation of poorly-coking coals and the conservation of the nation's diminishing supplies of the best coking coals.

Experimental.

Carbonisation.

Experience of the preparation of cokes in the laboratory has shown that the densest and strongest cokes are produced by approximating to the conditions of unilateral heating obtaining in an oven. This method of heating was used in the carbonisation of the coals

examined. The apparatus employed, which was similar to that described by Korten,[13] Damm[2] and others,[3,4,5,6,7,14] is shown in Fig. 1. A flat-bottomed iron vessel was provided with an iron piston fixed to the end of an iron tube as shown (Fig. 1). The annular clearance between the piston and the walls of the vessel was about $\frac{1}{32}$ in. The piston tube was screwed at its upper end and provided with a knife-edge, the height of which could be adjusted by a supporting nut. The temperature of the coal was determined by means of a thermocouple, the silica sheath of which was inserted through the piston tube and held in position by a gas-tight union fixed, as shown, to the top of the tube. Nitrogen was passed down

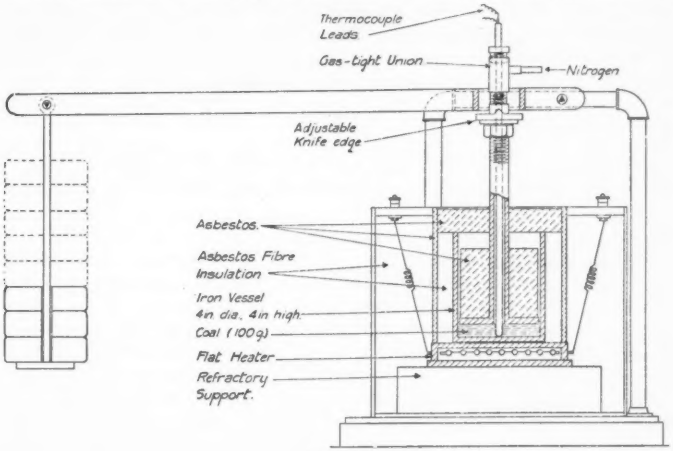

FIG. 1.

through the annular space between the thermocouple sheath and the piston tube and over the coal charge. The iron vessel was heated by a flat heater consisting of a series of closely-spaced nichrome spirals, which were embedded in alundum cement inside a shallow cylindrical iron case supported on a strong refractory base. The vessel and heater were lagged with loosely packed asbestos fibre.

Pressure was applied to the piston by means of a loaded lever acting on the knife-edge. In carrying out an experiment, 100 g. of the graded coal sample under examination were placed in the vessel, carefully levelled to give a layer of uniform thickness (approximately 2 cm.) and the piston and lever were placed in position, as shown in Fig. 1. The height of the knife-edge was adjusted so that the lever, when loaded, was approximately horizontal. The thermocouple and gas-tight adapter were placed in position, the thermocouple sheath being pushed down to the bottom

of the coal charge. Dry, oxygen-free nitrogen was passed through the apparatus *via* the side tube, and the coal charge was heated at the following rates by suitable adjustment of the current :

0–250° C. at 5° per min.
250–650° C. at 2° per min.
650–900° C. at 5° per min.

The temperature of the coke in the vessel was finally maintained at 900° C. for 20 min. The current was then switched off and the contents of the furnace were allowed to cool in the stream of nitrogen. The amount of swelling or contraction of the coal charge was determined from the movement of the lever over a scale. If the volume change of the charge during carbonisation was sufficient to deflect the lever arm more than a few degrees, the knife-edge was adjusted until the lever arm was again approximately horizontal. The position on the scale was also adjusted at the same time.

Examination of Cokes.

The apparent specific gravity and porosity of the cokes prepared were determined by an adapted form of the method described by

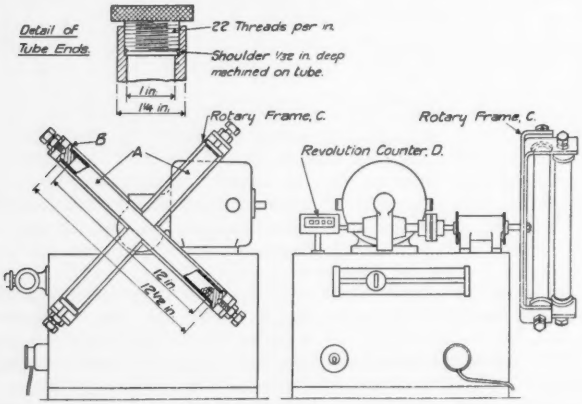

FIG. 2.

Braunholtz, Nave and Briscoe [15] for lump coke. Sampling errors were practically absent, since usually the whole of the coke could be used. After drying to constant weight, the coke was crushed and graded between 14 and 25 British Standard sieves for mechanical strength tests (*see* below). The coke passing the 25 B.S. sieve was reserved and later mixed with that used in the mechanical strength test. The combined sample was crushed to pass a 60 I.M.M. sieve

to give the average sample on which proximate analyses and real specific gravity determinations (*cf.* British Standard Specification No. 496) were made. Wet oxidation rates (*cf.* Blayden and Riley [16]) were determined on coke samples extracted from the average sample and graded between 60 and 100 I.M.M. sieves. Electrical conductivity measurements were also made on the same graded sample, under a pressure of 150 atm., by the method described by Balfour, Robinson and Riley.[17] The apparatus used by them was slightly modified by the provision of a lever arm in order to obtain the higher pressure. The glass tube containing the coke was also strengthened by sealing it into a thick-walled brass cylinder.

The apparatus employed for the assessment of the mechanical strength of the cokes is shown in Fig. 2. Two stainless steel tubes, 1 in. in internal diameter, with walls $\frac{1}{8}$ in. thick and burnished on the inside, were fitted with steel caps *B*, which could be screwed down on to a machined shoulder, as shown, to give a dust-proof joint. The distance between the inside flat faces of the steel caps when these were in position was exactly 12 in. The two tubes were mounted firmly in a frame *C*, which could be rotated at a constant speed by means of an electric motor and suitable reduction gear. The speed of rotation, which was determined by a stop-watch used in conjunction with the revolution counter *D* connected to the shaft of the frame, was adjusted by a resistance included in the motor circuit.

Two grammes of the coke, graded between 14 and 25 B.S. sieves, were placed in the tubes together with twelve steel balls ($\frac{5}{16}$ in. in dia.), the caps were screwed in position and the tubes mounted in the frame. The tubes were then rotated at a constant speed of 25 r.p.m. for 800 revolutions as shown by the counter. The amount of breakage which had occurred was determined by a careful sieve analysis of the resulting material. The steel balls were removed from the coke, and adhering powder was brushed into the sieves before making the sieve analysis. The test was carried out in triplicate, and the mean percentage weights of the original material (expressed to the nearest 0·5%) which remained on the 25 and 72 B.S. sieves were recorded as the micro-strength index, *e.g.*, 2/65, indicating that 2% and 65% of the original weight of coke remained on the 25 and 72 B.S. sieves, respectively. The sieving was carried out mechanically by means of an "Inclyno" test-sieve vibrator. The use of two tubes gave more uniform rotation and permitted simultaneous tests on two cokes.

The results of duplicate tests on the same coke generally agreed to within 0·5%, so that the index was probably significant within limits of about $\pm$ 0·5%. Application of the test to widely different types of carbon and to a number of commercial cokes indicated that the method gave a satisfactory differentiation of carbons likely to be met with industrially or in the course of laboratory investigations. Table I. illustrates the magnitude of the differentiation obtained when several varieties of carbon and coke were tested in this way.

A preliminary examination of the results on the basis of Rosin's law (Rosin and Rammler,[18] and Bennett[19]) indicated that crushing and impact breakage, as distinct from purely abrasive forces, were of importance in determining the magnitude of the index. There was no clear correlation between the micro-strength indices and the results of either shatter or abrasion tests made on corres-

TABLE I.—*Typical Micro-Strength Indices.*

Sample.	Shatter Index. Percentage on 2 in./percentage on 1½ in.	Micro-Strength Index. Percentage on 25/percentage on 72 B.S. sieves.
Retort carbon	...	35·5/72
Durham metallurgical coke	...	14/65
Gas coke (horizontal retort)	...	11/59·5
Electrode carbon (arc carbon)	...	8/51
Sugar charcoal	...	1/21
Wood charcoal	...	0/4
Cumberland oven coke (*a*)	72/85	21/70·5
„ „ „ (*b*)	61/81	23·5/71
„ „ „ (*c*)	...	13/64·5
Durham oven coke (*a*)	...	8/61
„ „ „ (*b*)	75/90	12/66
„ „ „ (*c*)	86/93	16/69
Lancashire oven coke	73/87	10/57
Scottish oven coke (*a*)	71/87	14/59·5
„ „ „ (*b*)	73/89	12/55
South Wales oven coke	84/93	16/66
Yorkshire beehive coke (*a*)	73/88	9/62·5
„ metallurgical coke (*b*)	86/93	15/68
„ furnace coke (*c*)	...	8/56·5
Durham coke, plant *A*:		
Carbonising time 24¼ hr.	75/90	5/66·5
„ „ 29½ hr.	86/93	16/69
Durham coke, plant *D*:		
Carbonising time 24 hr.	77/88	14·5/65
„ „ 27¼ hr.	82/91	16/66
Cumberland coke:		
From wall ends of pieces	69/83	25/73·5
„ inner „ „	63/77	14·5/67·5

ponding cokes (*cf.* Table I.). A correlation with the shatter index was hardly to be expected, since the latter is largely determined by the extent of fissuring, a factor which was absent in the small-size coke employed in the micro-strength test. There is little doubt, especially in view of the results described later, that the test gives a measure of those fundamental mechanical properties of coke which influence its mechanical strength.

The experimental method outlined above was applied in the examination of two Northumberland coals, the analytical character-

istics of which are shown in Table II. One of these coals, *C*57, had been stored for a long period in about $\frac{1}{4}$-in. size and had probably undergone some oxidation. It was only slightly agglutinating, and gave a friable, non-swollen button in the volatile matter crucible test. It was carbonised in < 60 I.M.M.-mesh size. The second coal examined, *C*518, was freshly mined, and, although regarded as a non-coking coal, showed definite tendencies to cake and gave a slightly swollen button in the volatile matter test. The coal *C*518 was carbonised in the following size gradings: $\frac{1}{8}$–$\frac{1}{20}$ in., 20–40 I.M.M., 60–100 I.M.M. and < 100 I.M.M. mesh. Each sample was carbonised under a series of pressures ranging from 0·2 to 20·4 lb. per sq. in. Special precautions were taken to ensure that the several samples were not oxidised either before or during carbonisation.

TABLE II.—*Analyses of Coals.*

Coal No.	Proximate Analysis.				Ultimate Analysis, Ash-free Dry Basis. %			
	Moisture. %	Ash. %	Volatile Matter less Moisture. %	Volatile Matter less Moisture, Ash-free Dry. %	Carbon.	Hydrogen.	Nitrogen.	Total Sulphur.
*C*57	5·9	4·5	35·5	39·6	81·47	5·25	1·79	1·94
*C*518	8·3	1·6	33·1	36·3	85·80	5·35	2·05	0·77

Results.

The results of the laboratory tests on the cokes are collected in Tables III. to VII. These Tables also record the volume changes during carbonisation. The initial contraction recorded is the percentage decrease in height of the coal layer, which occurred rapidly during the earlier stages of carbonisation (300–480° C. primary contraction). Within this range (which corresponded approximately with the plastic range of coking coals) the initial (primary) contraction was often rapid. It was followed by a relatively slow (secondary) contraction. The temperature at which the primary contraction was complete is shown in Tables III. to VII. The percentage difference between the thickness of the coke layer prepared at 900° C. and that of the original compressed coal is recorded as the final contraction.

Fig. 3 summarises the data obtained and illustrates the influence of applied pressure and coal size on the measured properties of the coke.

Carbonisation of the coal *C*57 (< 60 I.M.M. mesh size) under the minimum pressure (0·2 lb. per sq. in.) gave a dull, grey-black and friable coke which broke with the production of some loose powder.

This coke gave a zero micro-strength index. Increase of the pressure to 3 lb. per sq. in. during carbonisation gave a stronger, denser coke as a single piece showing no signs of fissures. The lustrous appearance and increased homogeneity of the coke suggested that agglomeration or binding of the coal particles had occurred more readily under

TABLE III.—*Carbonisation Data and Laboratory Examination of Cokes.*

Northumberland "non-coking" coal *C*57; size, less than 60 I.M.M.

	Applied Pressure. Lb. per sq. in.						
	0·2.	0·4.	3·1.	7·2.	10·0.	15·0.	20·4.
Carbonisation Data:							
Temp. range of swelling	None	None	None	None	None	None	None
Initial contraction. %	6·0	24·0	13·0	28·0	29·0	29·0	29·0
Final temp. of primary contraction. ° C.	470	460	440	425	440	435	440
Final contraction. %	6·0	24·0	15·0	7·0	29·0	30·0	31·0
Proximate Analysis:							
Ash. %	6·1	6·1	6·1	7·3	6·2	6·2	7·1
Moisture. %	1·3	2·9	4·1	4·1	2·1	2·2	2·5
Volatile matter less moisture. %	3·3	3·5	3·7	3·9	2·9	2·5	2·4
Fixed carbon. %	89·3	87·5	86·1	84·7	88·8	89·1	88·0
Wet Oxidation Rate, mg. CO_2 per $2\frac{1}{2}$ hr.	156	125	125	122	153	152	142
Apparent specific gravity	0·88	0·84	1·08	1·23	1·32	1·32	1·385
Real specific gravity	1·842	1·853	1·865	1·89	1·880	1·889	1·882
Apparent porosity. %	51	55	41	32	26	29	24
Total porosity. %	52	55	42	35	30	30	26
N.C.R.C. Micro-Strength Index:							
On 25 B.S.S. %	0	0	0·5	3·5	7·5	8·5	13·0
On 72 B.S.S. %	0	1·0	9·5	32·0	49·0	52 0	59·0
Specific conductivity. Mhos.	40	...	41	39	60	68	48

the higher pressure. Carbonisation at pressures up to 20 lb. per sq. in. progressively increased the density and strength of the coke. Several of the cokes thus prepared exhibited conchoidal fractures. Fissuring occurred with pressures greater than about 10 lb. per sq. in. and was marked in the cokes prepared at the higher pressures.

There was a marked increase in the apparent specific gravity and the micro-strength indices as the applied pressure was increased up to 10 lb. per sq. in.; further pressure increase had smaller effects.

The micro-strength of the coke made under 20 lb. per sq. in. was comparable with that of a metallurgical coke (Tables I. and III.). Increases in the apparent specific gravity and micro-strength were associated with corresponding decreases in the total and apparent porosity (Table III. and Fig. 3).

TABLE IV.—*Carbonisation Data and Laboratory Examination of Cokes.*

Northumberland "non-coking" coal *C*518; $\frac{1}{8}$–$\frac{1}{20}$ in. size.

	Applied Pressure. Lb. per sq. in.						
	0·2.	1·1.	2·3.	4·0.	9·6.	15·0.	20·4.
Carbonisation Data:							
Temp. range of swelling. ° C.	None	None	None	None	None	410–432 (0·3)*	408–460
Initial contraction. %	8·3	18	17	21	23	28	22
Final temp. of primary contraction. ° C.	400	465	435	470	470	450	490
Final contraction. %	3	19	17	39	31	34	34
Proximate Analysis:							
Ash. %	2·5	2·4	2·7	2·5	2·4	2·6	2·7
Moisture. %	2·6	2·4	2·3	2·7	2·4	1·9	2·7
Volatile matter less moisture. %	2·1	1·9	1·9	1·9	2·1	1·8	2·2
Fixed carbon. %	92·8	93·3	93·1	92·9	93·1	93 7	92·4
Wet Oxidation Rate, mg. CO_2 per $2\frac{1}{2}$ hr.	121	103	101	116	118	112	92
Apparent specific gravity	0·74	0·84	0·86	0·83	0·88	0·92	0·80
Real specific gravity	1·823	1·819	1·811	1·837	1·833	1·822	1·826
Apparent porosity. %	47	40	40	43	41	38	46
Total porosity. %	60	54	53	54	52	49	56
N.C.R.C. Micro-Strength Index:							
On 25 B.S.S. %	1·5	1·5	2·0	1·5	2·0	2·5	1·5
On 72 B.S.S. %	32·5	32·0	35·0	32·5	35·5	41·0	33·5
Specific conductivity. Mhos.	52	42	48	63	53	59	47

* Transient swelling, %.

Carbonisation of the several size gradings of the coal *C*518 at the low pressure (0·2 lb. per sq. in.) gave friable cokes, in which the particle structure of the original coal was to some extent retained in the coke. Increase of the applied coking pressure tended in general to give cokes of increased density and homogeneity, but also

tended to increase the extent of fissuring. Cokes prepared at relatively high pressures, especially those from the 60–100 and < 100 I.M.M. coals, exhibited the peculiar stratified structure sometimes observed in oven coke made from fine coal. The use of the higher pressures also tended to produce slight swelling in the temperature range 350–490° C. This effect was probably caused

TABLE V.—*Carbonisation Data and Laboratory Examination of Cokes.*

Northumberland "non-coking" coal *C*518; 20–40 I.M.M. size.

	Applied Pressure. Lb. per sq. in.					
	0·2.	1·1.	2·3.	10·0.	15·0.	20·4.
Carbonisation Data:						
Temp. range of swelling. °C.	None	None	None	None	418–438	400–470 (4·5)*
Initial contraction. %	19	17	23	31	35	16
Final temp. of primary contraction. °C.	420	440	470	460	470	500
Final contraction. %	18	22	24	33	40	19
Proximate Analysis:						
Ash. %	2·4	2·6	2·3	2·5	2·5	2·4
Moisture. %	2·1	3·6	2·8	1·8	1·9	2·6
Volatile matter less moisture. %	2·6	2·6	1·8	2·1	1·5	2·1
Fixed carbon. %	92·9	91·2	92·9	93·6	94·1	92·9
Wet Oxidation Rate, mg. CO_2 per $2\frac{1}{2}$ hr.	82	88	98	90	97	73
Apparent specific gravity	0·77	0·83	0·91	0·98	0·98	0·78
Real specific gravity	1·787	1·819	1·838	1·835	1·836	1·832
Apparent porosity. %	49	47	37	37	39	50
Total porosity. %	57	54	51	47	47	57
N.C.R.C. Micro-Strength Index:						
On 25 B.S.S. %	0	0	1·0	2·0	2·0	1·0
On 72 B.S.S. %	22·5	25·0	35·0	42·0	40·0	35·5
Specific conductivity. Mhos.	33	38	50	48	53	41

* Transient swelling, %.

by the entrapping of volatile products in the coal undergoing carbonisation under these pressures (*cf.* Tables IV.–VII. and Fig. 3).

The striking feature of the results was the definite maxima in the curves relating the carbonisation pressure to the micro-strength and specific gravity (Fig. 3). Corresponding minima were also obtained in the porosity curves. There was indeed a highly interesting general parallelism between the curves showing the variation with the carbonising pressure of the micro-strength, apparent

TABLE VI.—*Carbonisation Data and Laboratory Examination of Cokes.*

Northumberland "non-coking" coal *C*518; 60–100 I.M.M. size.

	Applied Pressure. Lb. per sq. in.							
	0·2.	1·1.	2·3.	4·0.	7·0.	10·0.	15·0.	20·4.
Carbonisation Data :								
Temp. range of swelling. °C.	None	None	None	None	None	420–515 (0·6)*	390–460 (0·6)*	400–480 (2·4)*
Initial contraction. %	19	31	25	34·5	42	33	40	27
Final temp. of primary contraction. °C.	420	450	435	445	420	450	460	480
Final contraction. % .	20	31	24	35	45	41	43	32
Proximate Analysis :								
Ash. % .	2·4	2·3	2·4	2·5	2·5	2·6	2·7	2·4
Moisture. %.	2·6	5·0	1·8	2·3	2·0	1·9	1·4	4·2
Volatile matter less moisture. % .	2·4	3·0	2·0	1·9	1·7	1·8	1·6	3·0
Fixed carbon. % . .	92·6	89·7	93·8	93·3	93·8	93·7	94·3	90·4
Wet Oxidation Rate, mg. CO_2 per $2\frac{1}{2}$ hr. .	78	81	85	89	89	101	87	74
Apparent specific gravity .	0·92	1·02	1·06	1·08	1·15	1·09	1·05	0·90
Real specific gravity .	1·834	1·838	1·845	1·835	1·856	1·842	1·850	1·824
Apparent porosity. % .	48	40	35	37	32	36	40	46
Total porosity. % . .	50	45	43	41	38	41	43	51
N.C.R.C. Micro-Strength Index :								
On 25 B.S.S. % . .	0	1·5	2·0	2·0	3·0	3·0	1·5	1·5
On 72 B.S.S. % . .	9·0	33·5	37·5	37·0	43·0	42·0	39·5	34·0
Specific conductivity. Mhos. .	45	42	50	68	57	68	70	42

*Transient swelling, %.

specific gravity and porosity, oxidation rate, electrical conductivity, and total contraction during carbonisation.

Fig. 3 provides an interesting picture of the influence of the size-grading of the coal *C*518 on the properties of the corresponding cokes. Although the micro-strength indices of the cokes prepared at pressures greater than 1·1 lb. per sq. in. from the $\frac{1}{8}$–$\frac{1}{20}$ in., 20–40

TABLE VII.—*Carbonisation Data and Laboratory Examination of Cokes.*

Northumberland "non-coking" coal *C*518; < 100 I.M.M. size.

	Applied Pressure. Lb. per sq. in.					
	0·2.	2·2.	7·0.	10·0.	15·0.	20·4.
Carbonisation Data :						
Temp. range of swelling. ° C.	None	None	420–460 (0·6)*	430–500 (0·6)*	390–480	400–480 (5·4)*
Initial contraction. %	21	32	28	32	31	22
Final temp. of primary contraction. ° C.	430	440	460	475	445	500
Final contraction. %	14	28	29	35	38	25
Proximate Analysis :						
Ash. %	2·8	2·9	2·9	3·3	3·2	2·9
Moisture. %	2·0	2·1	2·6	2·1	5·0	2·9
Volatile matter less moisture. %	1·6	2·1	2·4	2·1	2·15	2·5
Fixed carbon. %	93·6	92·9	92·1	92·5	89·6	91·7
Wet Oxidation Rate, mg. CO_2 per 2½ hr.	145	159	121	137	134	97
Apparent specific gravity	1·01	1·22	1·19	1·25	1·21	0·88
Real specific gravity	1·868	1·845	1·834	1·853	1·850	1·821
Apparent porosity. %	45	32	31	30	30	45
Total porosity. %	46	34	35	33	35	52
N.C.R.C. Micro-Strength Index :						
On 25 B.S.S. %	1·5	7·5	6·5	9·0	7·5	2·0
On 72 B.S.S. %	22·0	49·0	52·0	56·0	53·0	36·0
Specific conductivity. Mhos.	66	56	61	61	61	40

* Transient swelling, %.

I.M.M. and 60–100 I.M.M. mesh gradings were similar, the micro-strength indices of the cokes prepared at the lowest pressure (0·2 lb. per sq. in.) decreased with decreasing particle size of the coal. This observation suggests that at these low pressures inadequate agglomeration had caused the original particle structure of the coal to be retained to some extent in the coke, giving an abradable coke. A similar explanation may be advanced to account for the pronounced influence of pressure in the case of the cokes prepared from the

< 100 I.M.M. size coal. The cokes prepared from the latter grading exhibited in general micro-strength indices approaching those of commercial cokes (Table I.). This effect suggests that binding, under the influence of pressure, occurred more readily with the < 100 I.M.M. mesh size coal than with the larger size gradings.

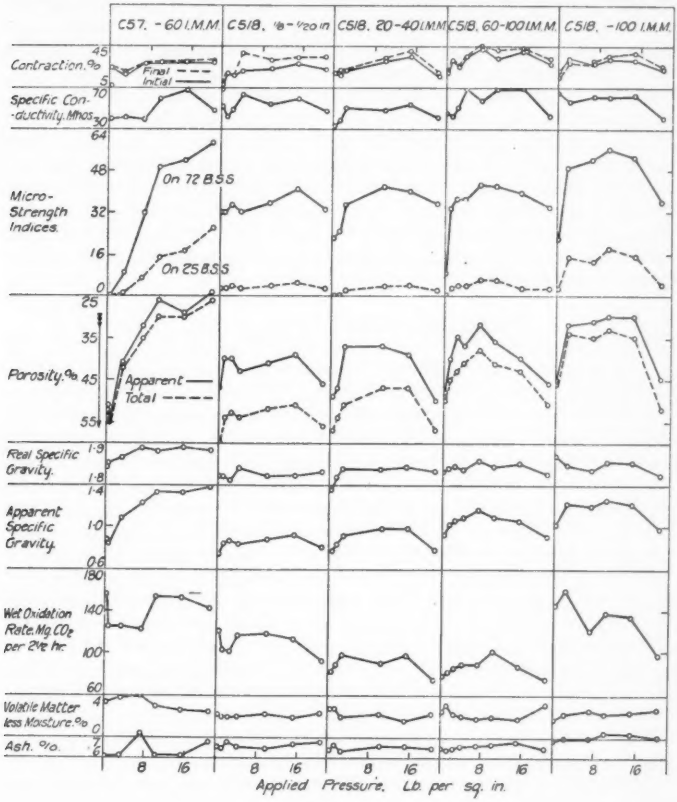

FIG. 3.

The < 100 I.M.M. material was, however, a mixture of different sizes, and was thus not strictly comparable to the larger, closely graded sizes.

It was noteworthy that the micro-strength indices of the cokes prepared under the greatest applied pressure employed, *viz.*, 20·4 lb. per sq. in., were very similar, probably as a result of the general

similarity of the effects of the swelling under these conditions (*cf.* the corresponding porosity data shown in Fig. 3 and the carbonisation data in Tables IV.–VII.). Decrease in particle size of the coal had a general tendency to decrease the porosity and to increase the apparent specific gravity of the coke. The changes in the real specific gravity of the coke were small. The difference between the total and apparent porosities gave a measure of the percentage volume of " closed pores " in the coke, and it is possibly significant that this difference exhibited a general tendency to decrease with decrease in particle size of the coal. The fall in the wet oxidation rates as the size grading of the coal was decreased to 60–100 I.M.M. size is probably significant, although it is difficult to explain. The markedly high wet oxidation rates of the cokes prepared from the < 100 I.M.M. size coal are, however, in keeping with the view that the identity of the original coal particles was partially retained in the coke; for it should be borne in mind when interpreting the wet oxidation results that coke graded between 60 and 100 I.M.M. sieves is employed in the test.

Discussion and Conclusions.

Several interesting correlations are at once obvious from the complete summary given in Fig. 3. A significant feature of the results was the very pronounced increase in the strength of the coke from *C*57 as the applied coking pressure was increased, the coke obtained under the highest pressure being comparable in strength to an average metallurgical coke. Similar phenomena were shown by the coal *C*518, although in this case they were modified by the swelling which occurred during carbonisation at the higher pressures.

It is now generally accepted that coke formation is dependent on the assumption of some degree of softening or fluidity of the coal particles during coking. With good coking coals this softening effect is appreciable even at slow rates of heating and may persist over 100–150° in the region of 400° C. (*cf. inter alia*, Foxwell,[20] Pieters, Koopmans and Hovers,[21] Davidson [22]). During coke formation the softened coal particles tend to cohere or to coalesce into a plastic mass, in which the individual particles become more or less merged. The " binding " or " cementing " action thus initiated is completed by the solidification of the material, as carbonisation proceeds, into a continuous but porous coke structure. Pressure has a pronounced influence on the binding action, partly as a result of the deformation of the particles and the increased area of contact produced. In the case of coking coals, adequate pressures are usually produced by the generation of gaseous decomposition products in the plastic coal, and in practice the pressures are also influenced by other factors, such as the rate of heating and the density of packing of the particles, as well as the nature of the coal.

Poorly-coking coals, on the other hand, do not readily soften at

slow rates of heating, and the temperature range of plasticity is relatively narrow (Pieters, Foxwell, *loc. cit.*). The fluidity tends to be increased with high rates of heating (Pieters, Koopmans and Hovers, *loc. cit.*), but at slow rates of approximately 1° per min. it is insufficient, with some coals, to bring about cohesion of the particles except under the influence of pressure, which the carbonisation process itself is not able to provide. The maximum binding effects of the transient softening of the poorly-coking coals at slow rates of heating are thus only obtained by the application of pressure (*cf.* Swietoslawski, Roga and Chorazy, *loc. cit.*).

The observed increase in strength with increase of applied coking pressure (Fig. 3) thus appears to be attributable in part to the improved agglomerating or binding effect under these conditions. Secondary effects were also evident at high applied pressures, when the swelling induced by the entrapped gases caused increased porosity and associated thinning of the cell walls, with consequent weakening of the material. Mott[23] and Pieters[24] have observed a similar decrease in the strength of laboratory-prepared cokes, as a result of swelling during carbonisation.

It is possible that, at the relatively high mechanical pressures employed, the cracking of the hydrocarbon vapours produced under pressure during the plastic state may also have influenced the strength of the cokes by inducing greater binding effects (*cf.* Fischer, Bahr and Sustmann, *loc. cit.*). The relative importance of this factor is, however, difficult to assess, but it may have a bearing on the increased strength of the cokes prepared from the finely crushed (< 100 I.M.M. mesh) coal and on the observed correlation between the electrical conductivity, wet oxidation rates and porosities (Fig. 3).

An interesting feature of the above results is the remarkably close correlation between the results of the micro-strength tests and the other experimental data. It indicates that the strength indices have a fundamental significance in relation to the mechanical strength of the coke substance. The new test should therefore serve a useful purpose in providing data supplementary to those given by existing tests such as shatter and abrasion tests.

The foregoing experiments were carried out for the Northern Coke Research Committee and the authors gratefully acknowledge their indebtedness to the Committee for permission to publish the results.

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[This paper was discussed jointly with the preceding one by Blayden, Noble and Riley.]

JOINT DISCUSSION.

The two papers by Blayden, Noble and Riley on "Some Experiments in a Small-Scale Cupola" and "The Influence of Carbonising Conditions on Coke Properties, Part I.," were discussed jointly.

Mr. E. C. EVANS (London) said that he would like at the outset to express the appreciation, which must be felt by Members of the Institute, that the authors had given them the opportunity at the present Meeting of considering some of their work, covering a very wide field.

He would like to venture a little further than Professor Riley, and see whether it was possible to discover any analogies between the results submitted by the authors and those of blast-furnace practice. After all, the real objective was to improve the coke quality in blast-furnace practice. In that connection, a very real difficulty presented itself, which the authors emphasised in the first paragraph of their first paper, where they said: "Despite the increased knowledge of the nature of coke and the formulation of tests which permit the quantitative measurement of its properties, the factors which influence its behaviour in the blast-furnace and cupola are still obscure." The question arose as to whether the paper threw any light upon those properties.

When an attempt was made to assess the value of coke for blast-furnace purposes, a number of tests dealing with its purely physical properties was available. It was possible to examine its combustibility, its reactivity and so on at fairly low temperatures; but the determination of its value for blast-furnace purposes involved a set of conditions entirely different from those obtaining when coke was burned at low temperatures. Recent work by a number of authorities, including Professor Riley himself, suggested that the mechanism of the combustion of coke at high temperatures was entirely different from the mechanism at low temperatures. In order to examine the properties of coke at high temperatures, it was necessary to adopt one of three methods. In the first place, it was possible to make a very large-scale test in the blast-furnace, a very expensive matter which required something of the order of 5000 tons of coke of uniform quality, and even then other factors might intervene which would make the test not altogether reliable. Secondly, there was the method described by Mr. Brooke in a very remarkable paper which he had presented to the Institute twelve months ago, where he compared the physical properties of the coke as determined daily in a laboratory with the blast-furnace results, and obtained a very remarkable correlation. The third method was that with which the authors had dealt in their first paper, the examination of coke in a small experimental cupola; and some of the results there shown appeared to be of considerable significance. The authors had shown

the influence of size, and mentioned the importance of having no fine coke in the furnace, and there was a number of points where comparisons with blast-furnace practice were immediately obvious.

In dealing with cupola experiments, there were two factors which in his opinion were of the greatest significance in blast-furnace operation. The authors were examining the cupola value of coke from two points of view : (1) the rate of melting, and (2) the melting temperatures. He thought that there was a distinct analogy between those properties and those which governed the use of coke in a blast-furnace. Blast-furnace performance was measured in practice by the output of the furnace, which meant essentially the rate of combustion per unit area in the furnace, the rate of melting, the cubic feet of air per hour—exactly the properties which the authors had been measuring. Another property which had been measured was the metal temperature, and again there was a definite analogy with the blast-furnace, particularly for those who were followers of the Johnson theory of the importance of available hearth heat. The higher the available hearth heat the greater was the furnace efficiency.

Taking those two measures of coke value, the authors had examined a number of different types of carbon, varying from anthracite carbon to metallurgical coke. There was one result which seemed highly significant : They had shown that with certain types of carbon a very high metal temperature was produced, but the rate of melting with such carbons was somewhat lower than the rate of melting with metallurgical cokes. Furnace cokes, on the other hand, gave a high melting rate with a low metal temperature. In one test, however, where they mixed 50% of foundry coke with 50% of retort carbon, there was an immediate increase in metal temperature, accompanied by a high melting rate.

He suggested that it was indicated that two conflicting properties were required in a blast-furnace coke. In the first place, a coke with a high melting temperature in the cupola, or, in other words, a high available hearth heat, was demanded, while at the same time a high porosity, giving a high rate of combustion in the blast-furnace, was required.

In the second paper, the authors showed that high micro-strength was associated with a low porosity, a property associated in the experimental cupola with low melting rates. The work suggested that two conflicting properties were required in coke for blast-furnace purposes ; this might explain the difference of opinion as to the properties desirable for blast-furnace coke. Some of his friends wanted a combustible coke. They were right; they wanted a coke which would give a high rate of combustion in the hearth. Others suggested that what they wanted was a coke of the highest mechanical strength, and of course a low proportion of breeze, and again they were right; but with the methods of manufacture at present available it appeared that those two properties were con-

flicting in character. A blend of two cokes, one of high and one of low porosity, might be worth considering.

In the second paper, dealing with the influence of carbonising conditions on coke properties, the possibilities of altering the quality of the coke from a given coal were discussed; and in this connection he paid a tribute to the number of attempts which had been made by the Northern Coke Research Committee to provide a test measuring the properties of coke desirable in blast-furnace practice. A number of new methods of testing had been devised by the Committee—the critical air blast (C.A.B.) test, the ignition temperature test, the wet oxidation test, and, in the present paper, a new test which the authors had suggested, that dealing with micro-strength. It was of extreme interest that those tests of micro-strength were closely allied with tests of other properties of coke. Using micro-strength as a test of quality, Professor Riley and his collaborators had started work on a problem of the greatest national importance, that of widening the range of coking coals. There was probably sufficient coking coal to meet present needs, but it was necessary to look ahead. The best coking coals were being worked out, particularly in individual districts, and it was a matter of the greatest importance that the range of coking coals should be widened.

It was of some significance in that respect that the observers of the Northern Coke Research Committee had been able, with a test which was suggestive in many ways, to increase the micro-strength of coke from a non-coking coal from zero up to that of a metallurgical coke. He could not imagine that a commercial battery of ovens would be equipped with a series of pistons at the top to apply the mechanical pressure required to bring about the desired result in practice, but so far it was only fundamentals which were being explored. He thought it was possible to devise methods, using the coal properties themselves, of applying pressure in practice, which would increase the strength of coke obtained from some of the poorly coking coals to-day, and in the future broaden the range.

Mr. D. Sillars (Middlesbrough) welcomed the work which had been done by Professor Riley and the Northern Coke Research Committee, and said that he did so because he thought it was the desire of many blast-furnace men, and particularly those not connected with coke-ovens themselves, to have some more work done upon coke *as* coke and not merely as a product coming from various mixtures of coal. Many people who worked blast-furnaces felt that, however useful and necessary the work which had been done on coal might be in order to produce various cokes, they would like to see the ground broken on the coke itself. The Northern Coke Research Committee, led by Professor Riley, had undoubtedly broken very valuable ground. A short time ago, Professor Riley produced a test which to some extent appeared to measure the rate of graphitisation of coke; and presumably the purpose of the

authors' present contribution was to take such cokes as had varying properties, including the variation in the oxidation test, and apply to them some sort of service test. In the early days of the Coke Research Committee it was hoped that service tests would almost immediately follow upon any change in the coking conditions, but both Professor Riley and Mr. Evans had enlarged on the enormous difficulties which presented themselves in conducting service tests on so complicated a piece of apparatus as a blast-furnace, where the test had to extend over very many weeks, if not months, and where the results were often vitiated by the fact that one factor so greatly overlapped another that it confused the issue.

In coming to the conclusion that the small coke gave certain indications which a blast-furnaceman would have expected, the authors had made an insufficient number of experiments upon the change in the blast quantity blown in. If the experiments could be extended—only one or two results were given—he thought it might bring out whether or not the real question of melting rate and temperature did not revolve round the rate at which the blast was applied. It would be noticed that the combustion figures did not quite follow the rate of blast added, but the number of figures was so small that he would not care to draw any conclusion from them.

One very interesting point in connection with the apparatus used was that with so small a unit as the 9-in. cupola it was surprising to find that the experimenters had been able to produce iron from it at as high a temperature as 1370° C. That was very creditable to those concerned, and showed that the conditions under which the cupola had been built and worked were not greatly different from the best conditions for operating a cupola in a foundry. He did not think that anyone would claim to get significantly higher temperatures than the authors had obtained from a cupola at such coke ratios as even 6 : 1, and therefore the loss by radiation and so on must be very near to the working conditions of the cupola. Would the authors say whether the temperatures given had been corrected for the emissivity of molten iron.

Altogether, the paper was suggestive rather than conclusive, and it was to be hoped that Professor Riley would continue to bear in mind, as he had done in the past, that many people were looking forward to some criterion of coke quality *as* coke quality. In discussing Special Report No. 18, reference had been made to an investigation into hearth conditions. It seemed to him that work such as the authors had done on the cupola might throw light more particularly on hearth conditions than on the blast-furnace as a whole.

With regard to gas analysis, some work which he had done many years ago in connection with the gases coming from cupolas had led him to the view that it was rather a hopeless business to obtain an average analysis from the gases. By "average" he meant one in which the spread was not so great that one could hardly reach

any conclusion as to whether the results were significant or purely chance.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), remarked that he was not interested directly in coke, but he would like to take the opportunity of congratulating Professor Riley on the general work which he was doing in this field, which was being followed with very great interest, and to join with previous speakers in expressing the hope that that work would be continued.

Looking at Fig. 3 in the second paper, it seemed to him a point of great interest that if one measured the micro-strength and increased the pressure under which the coke was made one found that a very small pressure gave almost a maximum result, and that successively higher pressures did not add to the strength. That seemed very strange; it looked as though a minimum of applied pressure would produce practically a maximum result to be achieved by the application of pressure. He would ask Professor Riley to explain why pressure achieved this result. The authors' remarks in the paper were an insufficient explanation, and merely stated the fact another way. It would be interesting to have an explanation of why this minimum of pressure achieved the result which it did.

There was one observation which he would like to make that might seem to show that he was talking about something of which he knew nothing. Those concerned with blast-furnaces were very interested in the strength of the coke, and yet when he went through their works and past their coke-ovens he found that they were pushing out the coke red-hot and playing water on it, involving rapid changes of temperature and the coefficient of expansion, and were really not adopting in that procedure a method which could be regarded as being particularly designed to give a non-shattering coke. Even if playing water on the coke did not materially damage it, it was surely necessary to consider residual stress. He thought the method adopted was very crude and indifferent, and was merely dictated by the idea of getting the job done as quickly as possible and getting the coke into the trucks, with little consideration for its ultimate service. He thought that that was fair comment.

JOINT CORRESPONDENCE.

Dr. G. E. FOXWELL (London), referring to the second paper, wrote that Professor Riley and he had this in common—they had both been pioneers. His own experiments and speculations on the plastic state of coal seemed to have set in motion a large volume of research on those lines which had been concerned with the mechanism of the softening of coking coals within that comparatively narrow range of temperature (generally 350° to 475° C.)

during which, in his view, the formation of coke occurred, and during which the quality of the resulting product was decided. Those experiments, which were published in a series of papers in *Fuel* (1924, vol. 3), were ancient history now, and were only referred to here by reason of their bearing on the present paper. Professor Riley and his co-workers at Armstrong College were pioneers in the investigation of another phase of carbonisation, the crystallographic structure of coke, which, although doubtless dependent to some extent upon the constitution of the coal and upon the treatment it had received at lower temperatures, was primarily a study of the coking process at temperatures higher than those during which the coal became plastic. Professor Riley's work and his own had, therefore, been strictly complementary. It was natural, however, that they should have a different outlook; he (the writer) was disposed to regard the coking process in terms of the softening and agglutination that occurred during the plastic stage and at no other time, and Professor Riley interpreted his own observations in terms of crystallographic structure.

It was unfortunately necessary at this stage to refer to another of his own publications, already mentioned by Professor Riley under reference 9. He had observed that, on heating a particle of coking coal, (*a*) a very small particle would soften and swell by reason of the internal generation of gases which could not readily escape through the plastic envelope, and (*b*) a larger particle did not possess the continuous plastic envelope, and the internal generation of gases resulted in the eruption on to the surface of cones and tongues of fluid material. That fluid material would later serve as the binding constituent of the coke. In coals deficient in fluid binding material the problem was to distribute the available material over the surfaces that remained non-fluid or non-plastic. It became obvious to him that that material would not flow of its own accord and must be forced. The force available was the internal pressure of those particles that would swell. Consequently he came to the conclusion that the coking qualities of the less plastic coals (and possibly of all coals) depended on setting up an adequate internal pressure in the plastic layer. That could be effected partly by the fine grinding of the coals and partly by increasing the pressure by mechanical means. The close parallelism between Professor Riley's results and those which the writer had published in 1924 and 1932 would be observed. Where they differed, he thought, was in the interpretation of the experimental results. He (the writer) ascribed the beneficial effect of pressure to the distribution of plastic material over the non-plastic surfaces of the durain and other constituents; Professor Riley, in the report of the Northern Coke Research Committee, stated that "mechanical pressure . . . brings the crystallites into closer contact and thus promotes fritting with a consequent increase of strength."

He thought it was probable that they were both right to some

degree. He had just explained his views, so that it was obvious wherein he considered that his own explanation was justified. Here was an experiment which showed that crystal growth might have something to do with increased strength due to mechanical pressure; many years ago, following the work of Evans and Sutcliffe, he compressed powdered Leicestershire non-coking coal in the cold to 10 tons per sq in. and carbonised the resulting briquettes. The resulting coke was extremely hard. The amount of plastic material in the Leicestershire coal was so small that he would not for a moment put this result down to better distribution of the fluid matter. No doubt Mr. Evans would be able to add to this solitary experiment some more extensive reminiscences of his own work.

The conclusion was thus reached that in order to improve the quality of the coke producible from the poorly coking, and non-coking, coals, the pressure to which the coal was subjected during the plastic stage (if any, or until a hard coke was formed) must be increased. In coke-oven practice, pressures up to about 1 atm. were met with in the plastic zones. These maximum pressures occurred only for very short periods, during which the two plastic zones that had been advancing from each heating wall met in the centre of the oven. When pressures of the order of 1 atm. were set up, the oven walls were damaged. Generally, the maximum pressure was well below $\frac{1}{2}$ atm. It was evident that a new technique would be necessary to take advantage of this principle of carbonisation under pressure that appeared likely to enable metallurgical coke to be produced from poorly coking, and even from non-coking, coals.

The importance of the work upon which Professor Riley and his colleagues were engaged would be obvious. Iron and steel industries must have coke of the highest quality; the higher the quality of the coke, the greater was the prospect of economies in operation. It did not appear that metallurgists had yet been able to state exactly what they meant by coke of a high quality. Certainly, attempts to put a financial value upon known and determinable properties of coke had not yet met with success. There could be no doubt, however, that the ability to resist breeze formation in the furnace must rank high in any estimation of coke quality. That was a criterion by which many furnace cokes were weak, and this work of Professor Riley's might lead to an improvement. Furthermore, our supplies of first-class coking coals were not illimitable; means of using inferior coals for the purpose must be found. Again, this was a practical aspect of Professor Riley's work. It now remained for the designer and inventor to discover methods for utilising this principle in industrial practice so that high-class metallurgical cokes could be made from the poorer coking coals—without increasing the cost above that of present coke-oven practice.

a minimum porosity. Table B reproduced values which had been obtained in the paper previously mentioned.

It was apparent from Table B that the authors' differentiation regarding the inverse relation between micro-strength and porosity appeared to apply only in a particular experiment such as the authors had made, and not in general to a wide variety of commercial cokes. Nevertheless, the fact that duplicate tests on the micro-strength machine agreed generally to within 0·5% indicated that the apparatus was a valuable one when considering the ultimate structure of cokes. Incidentally in attempts which the writer had made to correlate the microstructure with the micro-strength, there was an indication that cokes with a close structure had a low micro-strength.

Mr. F. HARGREAVES (Eastleigh, Hampshire) wrote that a primary consideration in which everyone, including the authors, must be specially interested was the applicability of results obtained when using such a small cupola to actual practice, for few people would accept the results without some reserve based on this aspect.

He could confirm from experience that coke of too small size gave cold metal, and that wide variations in the rate of driving the furnace were possible without any great effect on the temperature of the metal.

From experience also he could state that a coke was far from completely described by its ordinary chemical analysis and usual mechanical properties. There was a further major factor which, with a given metal-to-coke ratio, caused marked differences in temperature of the metal when running comparative trials of certain cokes, but he was unable to say what that factor was.

He would suggest to the authors that they consider the effect of water-quenching on coke as against dry-quenching. The former was very drastic, the latter gentle.

Mr. E. MORGAN and Mr. L. W. BOLTON (British Cast Iron Research Association, Birmingham) wrote that the authors were to be congratulated for their paper on the small cupola and for showing its possibilities in the way of carrying out practical tests on metallurgical cokes. They, at the British Cast Iron Research Association, had been particularly interested in these experiments, since they themselves had been using for the past eighteen months a 9-in. cupola similar in some respects to the authors', for investigating the effects of melting conditions in the cupola on the properties of the iron melted, with particular reference to the type of graphite obtained in the cast iron and to soundness in the castings, and in the course of which they had been using different types of cokes with somewhat striking effects on the properties of the irons melted. To some extent, the problems presented to them must have been similar to those encountered by the authors in

planning their investigation, and these had decided them to use the small-size cupola for the work.

From their experience with the small cupola they were in complete agreement with the authors regarding the feasibility of melting cast iron on a small scale under controlled conditions, and they would also suggest possibilities of carrying out tests in it on the raw material going into the foundry, such as pig irons as well as cokes. It was surprising to note that the authors did not refer to any particular difficulties that they might have encountered in the running of the 9-in. cupola, although the 6-in. dia. cupola was discarded, particularly since they varied the conditions of air blast, cokes, &c., within somewhat wide limits. In the early stages of their own investigation they had had some difficulty in getting the charges to settle down uniformly in the cupola, avoiding bridging, blocked tuyeres, &c., which seriously handicapped the work. Particularly was this troublesome when investigating the effects of varying the height of bed, since it could never be guaranteed that the effects produced were not due to somewhat abnormal melting conditions arising from the above-mentioned causes. Incidentally, these troubles occurred when methods somewhat similar to those of the authors were used in preparing the bed before putting on the charges. The present method employed consisted in lighting a small fire on the bottom of the cupola, coking up as far as the tuyeres, and allowing the coke to burn through up to this level, at which stage the bed was made up to its proper height, the charges were put on and the blast was started without any waiting period for soaking. They had found that by using this method, bridging troubles disappeared almost entirely, the charges settled down more easily and the metal temperature at the spout was higher. They would be interested to know to what extent the authors considered their results to have been affected by such difficulties.

The authors had taken the temperature of the metal at the tapping spout with other data as giving an index of the value of coke for melting cast iron in the cupola. Without wishing to criticise this procedure, although it would be admitted that the tapping temperature was very largely controlled by the depth of incandescent coke from the melting zone to the tuyeres, the writers would like to ask the authors whether the same class of iron had been used in all these experiments. They had repeatedly found that with their small cupola such materials as low-carbon hematites, low-phosphorus and steel mixtures had much higher tapping temperatures than irons containing about 1% of phosphorus, differences of the order of 130° C., as measured by means of the platinum/platinum-rhodium couple, being obtained. Furthermore, it had been found that by varying the conditions in the cupola—blast, bed height, &c.—bigger differences in temperature were obtained with hematite and steel mixtures than with 1% phosphoric irons. They pointed this out because, by a suitable choice of metal

to be melted, it might be possible to obtain greater temperature variations than those noted in this paper.

The authors had not made any reference to slag in the cupola, and the writers would be interested to know whether the type of slag formed had any influence on the behaviour of certain types of cokes used. A thick, slow-running slag, for instance, might have a considerable effect in obstructing the passage of the gases through the bed.

The Association had also recently tested a wide variety of cupola cokes in two commercial cupolas in conjunction with the London Midland and Scottish Railway Company. The results were reported in June, 1937, to the Institute of British Foundrymen and were given in the *Foundry Trade Journal* for July 15, 22 and 29, 1937, including those on cokes 316 and 317 referred to by the authors on p. 38 P.

A considerable amount of work on the relation between the air supply, output and temperature had been done in Britain and abroad by foundry engineers and metallurgists, and the interest of those primarily concerned with coke quality could not fail to be valuable.

AUTHORS' REPLY.

Professor RILEY replied that Mr. Evans had raised the question of the method of applying mechanical pressure on a large scale. It could not, of course, be done by pistons, but the results obtained suggested that in the case of ovens used for the coking of inferior coals, modification in the design of the oven, particularly in regard to the height, might be beneficial. What was perhaps more important, however, was the guidance on blending which further work would provide. The gases generated during coking were responsible for the development of the pressure necessary for the formation of a strong coke. The experiments showed that there was an optimum pressure and that coke strength was very sensitive to small changes in mechanical pressure. This suggested that the objective of blending should be the attainment of these optimum pressure conditions in the oven. The work was being continued.

Mr. Sillars had raised the question of the study of blast-furnace reactions with a cupola of the type described. Some preliminary experiments in this direction had been done and it had been found possible in a slightly modified cupola, but difficulty had been experienced in getting the hearth hot enough to prevent the iron from freezing as it came down. There was some promise of being able to work a small blast-furnace, which would make possible certain investigations at a relatively low cost. With regard to Mr. Sillars' remarks concerning the metal temperatures, the reported temperatures were not corrected for the emissivity of the metal.

Dr. Hatfield had touched on a very interesting point with

regard to the optimum effect of a very small pressure. Since the experiments in question had been completed, they had continued the work up to pressures of nearly 500 lb. per sq. in. and had found with certain coals that nearly all the effect took place within the first 40 lb. pressure, so that the important influence in increasing the strength did occur within an initial small range of pressure. He would not like to say what the cause was, but he thought that it was due to the increased area of contact of the plastic coal particles and probably also to a packing together of the graphite crystallites in the carbon.

The effect of water-quenching was a matter which had been studied. Strangely enough, it had not a very large effect on the strength of coke. It was, of course, an economic question. There were certain plants which used dry-quenching.

Dr. Foxwell's communication contained several observations which were of great interest. He attributed the beneficial effects of pressure to the distribution of plastic material throughout the coal. In the experiments reported, the authors were not immediately concerned with the explanation of the plasticity developed during coking. It was sufficient to consider that plasticity was developed within a certain temperature range during coking. The consolidating effect of compression at this stage was apparently a dominant factor influencing coke strength. The results obtained suggested, indeed, that the plastic condition of the poorly coking coal was more related to the " flow " of pitch under pressure than to softening as a result of the distribution of fluid material as postulated by Dr. Foxwell. Professor Riley agreed that his own and Dr. Foxwell's views were to a large extent complementary.

Dr. O'Neill had suggested that correlation of the results of small-scale and large-scale cupola tests was of importance. Professor Riley was in agreement with this but regretted that the cost was prohibitive at present, and he doubted if systematic work could be carried out in full-scale cupolas under practical working conditions, which usually involved a large number of restricting factors. In reference to Dr. O'Neill's remarks on the greater differentiation of cokes when the working ratios were suitably adjusted, Professor Riley agreed that this procedure would have been preferable in most of the experiments, but here again the cost and time involved prohibited any extensive use of this method of examination. Dr. O'Neill had also enquired as to the nature of the abrasion test with which the results of micro-strength tests had been compared. The test involved in these comparisons was the Cochrane drum test. The conclusion that high micro-strength indices were generally associated with low porosity of the cokes naturally referred particularly to the coals examined in the present paper and to the method of carbonisation employed.

Professor Riley was pleased to note that Messrs. Morgan and Bolton had been able to apply successfully a similar small-scale

cupola to the investigation of melting conditions in the cupola. Many difficulties had naturally to be overcome before the 9-in. cupola was run satisfactorily. It was found that the 6-in. dia. cupola which was first employed was unsuitable for the study of, for example, the influence of coke size, although under certain conditions this small cupola worked satisfactorily for the melting of iron. Large-size coke could not, however, be used. Difficulty had occasionally been experienced in the operation of the 9-in. cupola as a result of bridging. This was, however, readily detected during the run and was easily overcome by forcing down the charge in the shaft with an iron rod.

During the course of the experiments the authors had also observed that the metal temperatures were influenced by the quality of the iron employed. They had taken precautions to eliminate any variations arising from this cause. The original metal employed was foundry scrap and consisted largely of " risers " from castings of the same metal. These were melted in preliminary experiments, and batches of similarly pretreated metal were employed in the respective comparative tests. The metal temperatures in the series of experiments were thus comparable. In the experiments described a fairly freely running slag had been obtained, although in certain other experiments, which were not reported, a thick pasty slag had sometimes been obtained when difficulties were experienced in the running of the cupola. It was usually associated with marked oxidation of the iron and in most cases had a deleterious effect on the running of the cupola.

THE THOMAS-GILCHRIST BASIC PROCESS, 1879–1937.[1]

By F. W. HARBORD, C.B.E. (London).

(Portraits = Plates II. to V.)

Synopsis.

The author gives a short account of the early life and training of Sidney Gilchrist Thomas and of the development of the Thomas-Gilchrist process from the early experiments carried out by Gilchrist and Thomas in the 6-lb. converter to the present-day production of 90,000,000 tons of basic steel per annum.

After describing the experiments at Blaenavon, and the assistance given by the late Mr. E. P. Martin, he shows how, by the enterprise of Messrs. Bolckow, Vaughan & Co., Ltd., acting on the advice of the late Mr. E. Windsor Richards, the commercial and technical possibilities of the process were demonstrated to the world. He refers to some of the difficulties encountered and indicates how, by the courage and persistence of Mr. Windsor Richards, success was finally achieved. He then traces the development of the process on the Continent, in Great Britain, and in America, and points out that the general tendency in recent years for the basic open-hearth to supersede the basic Bessemer is largely a matter of the wide distribution of suitable ores containing insufficient phosphorus for producing a pig iron suitable for basic Bessemer practice, and how this is especially noticeable in America, where 43,000,000 tons of steel were produced by the basic open-hearth process last year (1936).

The conditions under which the basic Bessemer had to operate in Britain with the ores available are sketched, and the re-introduction in this country of the basic Bessemer process by Messrs. Stewarts & Lloyds, Ltd., at Corby is referred to.

The author then deals with the influence which the basic process has had on the railway, shipbuilding, and engineering industries, and on the world as a whole, and points out that the present world production of basic steel involves the mining of not less than 250,000,000 tons of phosphoric ore per annum, which otherwise could not have been used for steelmaking, and that since the introduction of the Thomas-Gilchrist basic process it is estimated that not less than 22,000,000 tons of phosphoric acid as basic slag have been returned to the land to enrich the soil.

Finally, the author refers to Thomas as a man and the loss to the world by his early death.

It is just over fifty-eight years since, by the enterprise of the Ironmasters of Middlesbrough, the commercial possibilities of the basic Bessemer process invented by Sidney Gilchrist Thomas were demonstrated at the Works of Messrs. Bolckow, Vaughan & Co.,

[1] Received August 5, 1937.

Ltd., then under the management of the late Mr. E. Windsor Richards. To-day 90% of the world's output of steel, or about 90,000,000 tons, is produced annually by the basic Bessemer and basic open-hearth processes.

For some years prior to 1879, the shortage of ores low in phosphorus suitable for producing low-phosphoric pig iron for the acid Bessemer and open-hearth processes was causing anxiety to our leading steelmakers, as only about one-tenth of the then known iron ore deposits in Europe could be used for steelmaking. In 1872, the late Sir Lowthian Bell wrote " The limit to the production of Bessemer pig is the want of ores free from phosphorus. The hematites [non-phosphoric ores] of this country under the sudden demand have doubled in price, and speculators of all kinds are rushing off to Spain, where tracts of land, conceded without any payment a few months ago by the government of that country, are said now to be worth large premiums." [1]

Sidney Gilchrist Thomas, born on the 16th April, 1850, was the son of William Thomas, a Civil Servant, and Melicent Thomas (*née* Gilchrist). He was educated at Dulwich College and intended to study medicine, but owing to the sudden death of his father he decided against entering on a medical career, and obtained through a relative a nomination for the Civil Service and was appointed Clerk to the Magistrate at the Marlborough Street Police Court in 1867. In 1868 he transferred to the Thames Police Court, where he remained until 1879.

He then (1867) began to study science privately, and a little later entered as a student at evening classes at the Birkbeck College, where he attended lectures in chemistry, physics, mechanics, &c. He later attended a course of lectures on metallurgy by Mr. Chaloner, during which the importance of the dephosphorisation of pig iron in the Bessemer process was emphasised, and the great possibilities which the solution of this problem offered appealed so strongly to Thomas that he at once began to study the subject.

He first approached the problem by considering the reason why phosphorus was not eliminated during the blow in the acid Bessemer converter, and gradually the reason why phosphorus was not removed began to take definite shape in his mind. Finally he came to the conclusion that the phosphorus was oxidised like all the other impurities in the pig iron, but that under the conditions of high temperature any phosphate of iron formed in the presence of the highly siliceous slag was immediately dissociated and the phosphorus passed back into the metal. It was well known that lime had a strong affinity for phosphoric acid, but it was impossible to add lime to molten metal in a converter or vessel lined with siliceous material, as the lime would immediately attack and flux the lining. The

[1] " Chemical Phenomena of Iron Smelting." *Journal of the Iron and Steel Institute*, 1871, No. I., p. 85, 277; No. II., pp. 67, 277; 1872, No. I., p. 1. Reprinted as a text-book in 1872.

problem then gradually narrowed itself down to finding a lining which would withstand the action of lime or some similar strong base at the high temperature developed during the Bessemer blow. On this Thomas now concentrated the whole of his energies.

He began his early experiments in a crucible in a room fitted up as a laboratory at his mother's house, but of course was unable to get anything like the temperature necessary to obtain satisfactory results. He then, in 1876, decided to approach his cousin Percy Carlyle Gilchrist, who at this time was chemist at the Cwm Avon Steelworks. At first Gilchrist was not very enthusiastic, but the persistence of Thomas prevailed, and after considerable delay some experiments suggested by Thomas were begun, but even at a steelworks there was great difficulty in carrying out the preliminary experiments without great expense.

About this time Percy Gilchrist resigned his position at the Cwm Avon Steelworks, and was appointed chemist at the Blaenavon Steelworks, and there the early experiments were carried out.

The first experiments were made in crucibles lined with limestone or lime, and later a small converter lined with limestone, with silicate of soda as a binder, holding 6 lb. of molten metal, was installed.

In 1877 Thomas made arrangements to have Saturdays free from the Police Courts, and he then began to travel down to Blaenavon on Friday night and return on Sunday night, and he and Gilchrist spent each week-end carrying out experiments. For nine months experiments with Northamptonshire pig iron, which contained about 1·5% of phosphorus, were carried on in a miniature 6-lb. converter lined with the limestone bricks. Promising results were obtained, but owing to the difficulty of working on such a small scale, and especially of maintaining the heat in such a small converter, the results varied considerably and complete and regular dephosphorisation could not be relied upon. The results obtained, however, were sufficient to demonstrate that, with a basic lining and lime additions to the converter, phosphorus could be removed and retained in a basic slag.

The regular week-end visits of Thomas to the works naturally did not pass unnoticed, and early in 1878 Mr. Edward P. Martin, the General Manager of Blaenavon Works, said to Mr. Gilchrist, "It is evident that you young men have some secret experimental work on hand; do you not think it would be well if you took me into your confidence?" This was done, and Mr. Martin was so much impressed by the results of the experiments that he at once afforded facilities at the works for experiments on a larger scale and promised similar facilities at the Dowlais Works. The question of finance was now becoming serious, as patents had to be applied for in different countries, and this difficulty was met by Mr. Martin personally offering to purchase a share in the patents, which not only relieved the patentee from immediate financial anxiety, but

greatly strengthened his position by the active co-operation of a steel manufacturer with wide technical and business experience.

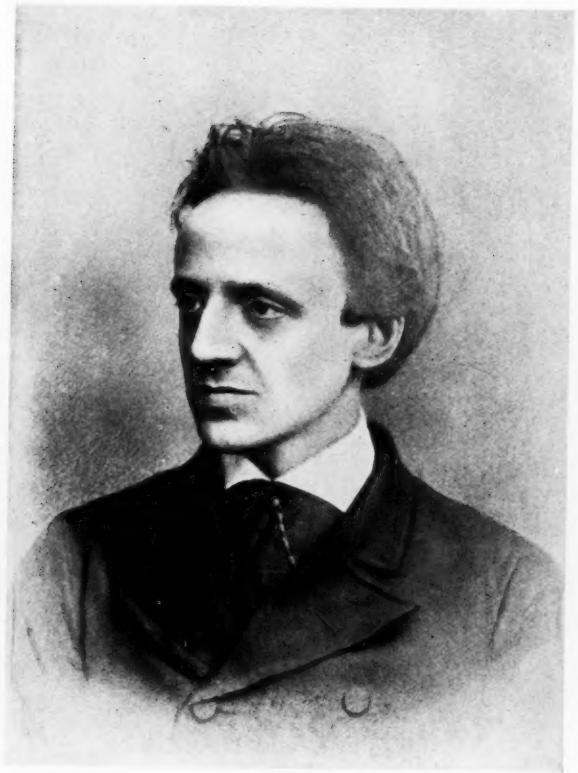
Mr. Martin arranged for a small fixed converter, capable of holding 3 or 4 cwt. or metal, to be erected at the Blaenavon Works, and some 50 or 60 " blows " were made and the metal and slags analysed. Gradually the essential conditions for dephosphorising were determined, and the advantage of adding lime to form a basic slag and protect the lining from fluxing was established. The next step was a series of experiments in a converter holding 12 cwt. of metal, but in this vessel the lining of bricks made of limestone, which had given promising results with the small converter, proved unsatisfactory, as they quickly disintegrated. Both Sidney Thomas and Percy Gilchrist always recognised how much they owed to Mr. Edward Martin, not only for the assistance given in carrying out the early experiments, but for his wholehearted support and encouragement.

At the Autumn Meeting of the Iron and Steel Institute held in Paris in 1878, Thomas presented a paper entitled " On the Elimination of Phosphorus in the Bessemer Converter," but its importance was not realised by the Council, and, as precedence had to be given to papers by foreign members, there was not time to read the paper, and its discussion was postponed until the May Meeting in 1879. At the Paris meeting Mr. E. Windsor Richards, then General Manager of Bolckow, Vaughan & Co., Ltd., met Thomas, and was so impressed with the importance of the results disclosed in the paper and by the personality of the author that he advised his Directors to allow him to investigate the process. For this purpose in October, 1878, he went down to Blaenavon with Dr. Stead, the Consulting Metallurgist to his Company, and saw some experimental blows. This visit satisfied him that the process had great possibilities, and, acting on his advice, the Directors of Messrs. Bolckow, Vaughan & Co., sanctioned the carrying out of a series of experiments at their works in Middlesbrough.

The first experiments were carried out at Bolckow, Vaughan's works in two 30-cwt. converters.

Thomas had realised from the first that a converter lining which would last a reasonable time was essential to commercial success, and he and Gilchrist had been working night and day on this problem. Different limestones, from mountain limestone to dolomites, were tried, and the bricks were burnt at various temperatures, the most promising results being obtained with dolomite bricks burnt at the highest temperatures obtainable in existing kilns.

One of the main troubles was the great shrinkage of the bricks during burning, and those interested will find in the contribution by Mr. Windsor Richards to the discussion on the original paper of Thomas and Gilchrist read before this Institute in May 1879, a very full account of the difficulties they encountered, and how they overcame them. When the bricks were burnt at the highest temperature

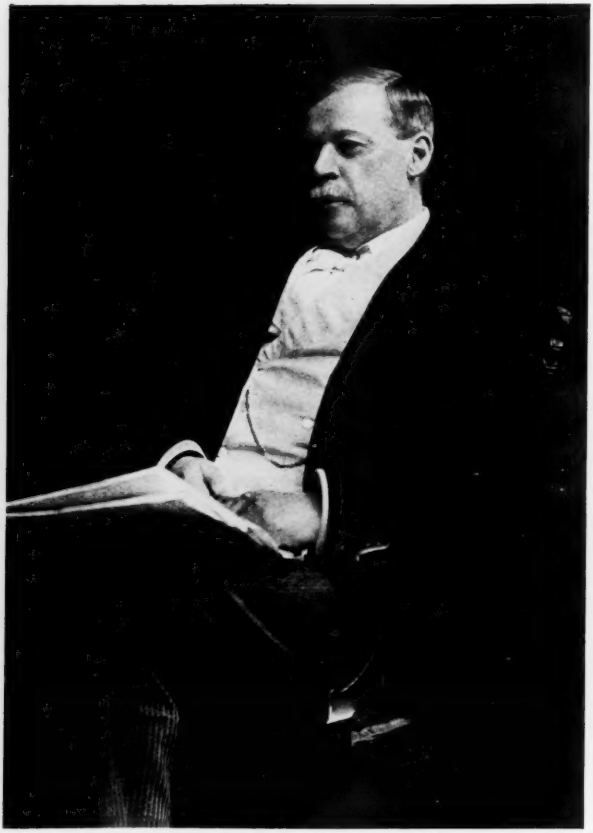


SIDNEY GILCHRIST THOMAS.

(Block kindly lent by Messrs. Dorman, Long & Co., Ltd.)

[*Harbord.*

[*To face p.* 80 P.



PERCY CARLYLE GILCHRIST, F.R.S.

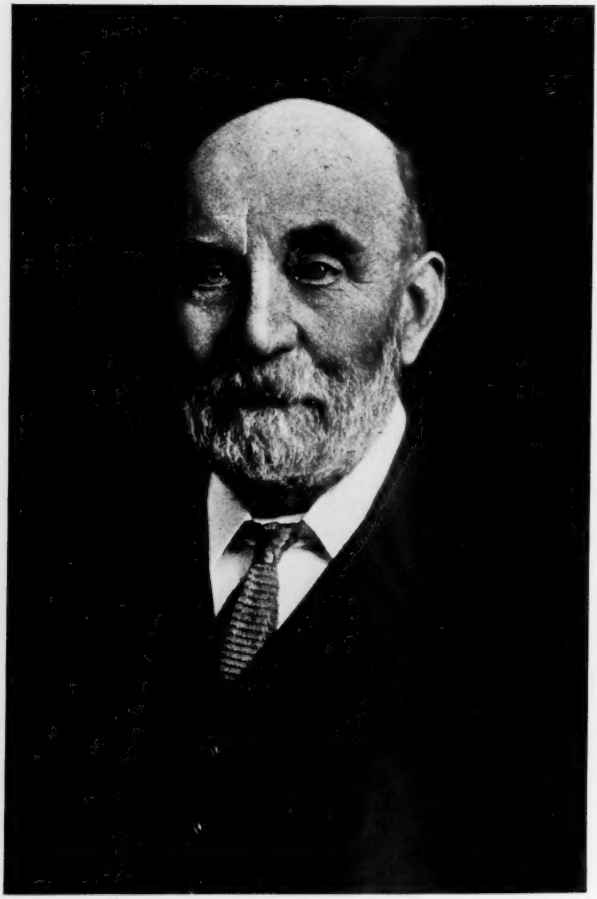
(Block kindly lent by Messrs. Dorman, Long & Co., Ltd.)

[*Harbord.*

E. WINDSOR RICHARDS.

Block kindly lent by Messrs. Dorman, Long & Co., Ltd.)

[*Harbord.*



DR. J. E. STEAD, F.R.S.

(Block kindly lent by Messrs. Dorman, Long & Co., Ltd.)

[*Harbord.*

[*To face p.* 81 P.

available, the warping due to shrinkage was so serious that it was extremely difficult to use them; regrinding the burnt bricks and again moulding them was tried, which, although it effected a great improvement, did not completely get over the trouble. After many trials with dolomite bricks burnt at varying temperatures, the difficulty of shrinkage was finally overcome by burning the dolomite in a cupola at such a high temperature that it was completely shrunk before being moulded into bricks. The first cupola plant for making shrunk basic material in England was erected at Coxhoe, Co. Durham. A dense semi-fritted material was thus obtained, which could be made into bricks and used without any risk of further shrinkage at the temperature of the converter. The use of silicate of soda as a binder, however, was not satisfactory, as when ground rammed material was used as a lining it expanded, and various other binders were tried. Thomas in some earlier experiments had tried tar as a binder; Edward Riley had patented the use of petroleum, and it was suggested by one of the staff of Bolckow, Vaughan & Co. that tar should be tried. This was done, but as soon as the bricks were heated they lost their coherence and tar was for a time abandoned. Later Thomas suggested boiling the tar to remove the last traces of moisture before use and ramming the ground shrunk dolomite and tar into the converter with a red-hot rammer, and the converter in which the first successful experimental blows were made at Bolckow, Vaughan's works was lined in this way.

In the experiments at Middlesbrough, Thomas desired if possible to do without the after-blow, as he knew that fears of over-oxidation would prejudice his process. In the early experiments at Blaenavon, by mixing oxide of iron with the lime additions and so obtaining a fluid oxidising slag early in the blow, he had obtained a very considerable removal of phosphorus before the drop of the flame, and he hoped that in a larger converter, in which it would be easier to maintain a fluid slag, he might be able to dephosphorise in this way, and other metallurgists associated with him in these experiments were of the same opinion. A number of experiments were tried on these lines at Bolckow, Vaughan's, but it was found that the removal of phosphorus could not be relied upon, and to ensure the regular and complete removal of the phosphorus to 0·04% an after-blow was essential. The first " official blow " in the 30-cwt. converter was made on the 4th April, 1879, and the first detailed record in the possession of the Company of a blow in which samples were taken at intervals to show how the carbon, silicon and phosphorus were removed, is dated 3rd May, 1879. As soon as the success of the experimental trials became known, steel manufacturers, metallurgists, and steelworks managers from different parts of the Continent at once asked permission to visit Messrs. Bolckow, Vaughan's works to see the process in operation.

Early in April, 1879, Herr Joseph Massenez, a Director of the

Hoerde Works, obtained permission from Mr. Windsor Richards to visit his works and see the process in operation, and he, with Herr Richard Pink, steelworks manager at Hoerde, went to Middlesbrough. They were so satisfied with what they saw that they at once went to London to negotiate with Thomas for the rights for Germany and Luxemburg. When they arrived in London they found that Herr Gustav Pastor, the manager, and Dr. Grasz, the engineer of the Rheinische Stahlwerk at Ruhrort, were already negotiating, but finally an agreement was arrived at for the Hoerde Works and the Rheinische Stahlwerk to hold in common the Thomas patent rights for Germany and Luxemburg. This agreement was settled on the 21st April, 1879, and within a few weeks Herr Massenez secured the patent rights of the Thomas process for Austria-Hungary. The first basic Bessemer heat at the Hoerde Works was blown in a 3-ton converter on the 22nd September, 1879, and by a remarkable coincidence the Rheinische Stahlwerk began to operate on the same day. On this day the first basic steel rails were rolled on the Continent, and were in every way satisfactory.

On the 14th December, 1879, Herr Massenez, at the meeting of the Technischer Verein für Eisenhüttenwesen held at Düsseldorf, reported on the results obtained at Hoerde. He said that he had produced excellent steel with only 0·03% of phosphorus from low-silicon white iron containing over 2·0% of phosphorus; he definitely stated that the high percentage of silicon in the pig iron used for the acid Bessemer process was unnecessary and undesirable for the basic process, as the heat developed by the oxidation of the phosphorus was sufficient to maintain the temperature of the finished metal for casting into ingots.

At this time the patent position in Germany was causing considerable anxiety, as a group of German Ironmasters decided to contest the validity of the German patents. Although Thomas was able to read technical German, his knowledge of the language was limited, and with characteristic energy he at once began an intensive study of the German language and German patent law to enable him to assist his legal patent advisors in Germany. After a hard fight the German Courts decided in Thomas' favour on the 22nd November, 1879.

At the May Meeting of this Institute in London in 1880, Herr Richard Pink gave the results of the first six months' operations of the basic process at the Hoerde Works,[1] and said that his recent experience confirmed Herr Massenez' statements as to the satisfactory results obtained with low-silicon pig iron containing manganese. At the Autumn Meeting at Düsseldorf in 1880 Herr Massenez[2] said that the progress made at Hoerde was most satisfactory, and that in respect of both the quality of the finished

[1] *Journal of the Iron and Steel Institute*, 1880, No. I., p. 57.
[2] *Ibid.*, No. II., p. 475.

material and the yield they were quite satisfied, and this was confirmed by Professor Wedding and Professor Finkener.

Meanwhile Messrs. Brown, Bayley and Dixon, after their representative had visited the Hoerde Works and seen the results obtained, decided to try the process at their works in Sheffield, and on the 29th November, 1879, the first blow was made with a mixture of Lincolnshire white and No. 4 forge irons, and the results of their experiments were given in a paper by Messrs. Holland and Cooper on the "Manufacture of Bessemer Steel and Ingot Iron from Phosphoric Pig"[1] at the May Meeting of this Institute in 1880. This converter was lined with bricks made of burnt dolomite with petroleum as a binder according to a patent of Mr. Edward Riley, but this lining did not give satisfactory results. Although they had lining troubles, and mechanical difficulties owing to the construction of the converted plant, so far as the production of high-class steel was concerned the results were quite satisfactory, and confirmed those obtained at Messrs. Bolckow, Vaughan's works and on the Continent.

Since the first experiments in 1879 at Bolckow, Vaughan & Co.'s works, the early difficulties had been gradually overcome, and Mr. Windsor Richards in May, 1880, when discussing the paper by Messrs. Holland and Cooper above referred to, announced that his Directors were so satisfied with the results obtained that they had decided to erect an up-to-date plant at their works especially designed to operate the basic Bessemer process.

When the experiments were commenced at Bolckow, Vaughan's, Gilchrist resigned his position at the Blaenavon Steel Co. and devoted all his time to supervising the experiments at these works, and in May, 1879, Thomas resigned his position at the Thames Police Court and undertook all the business negotiations in connection with his process.

No one realised more than Thomas how much he owed to Mr. E. Windsor Richards for demonstrating to the world the possibilities of his process. During the experimental period at Bolckow, Vaughan's, in the face of many unforeseen and unexpected difficulties, Mr. Windsor Richards never allowed himself to lose heart, but faced each difficulty as it arose, until by his persistence, courage and determination success was eventually achieved. In acknowledging the award of the Bessemer Gold Medal in 1883, which he was too ill to receive in person, Thomas wrote to the President of this Institute, and, after identifying his colleague Mr. Gilchrist equally with himself as entitled to receive any credit for the success of the process, and stating how much this was due to Gilchrist's great exertions and untiring energy, he said "The present position of dephosphorisation has only been rendered possible by the frank, generous, and unreserved co-operation of Mr. Windsor

[1] *Journal of the Iron and Steel Institute*, 1880, No. I., p. 79.

Richards (to expatiate on whose great contributions to the development of the process would be in Cleveland almost an impertinence), of our earliest and consistent supporter Mr. Martin, of Mr. Riley and Mr. Cooper, and of the numerous and able colleagues we have found at Hoerde and Ruhrort, Creusot, Angleur, Witkowitz and elsewhere."

In 1881, eighteen months after the possibilities of the process had been demonstrated at Middlesbrough, the basic Bessemer process was operating at twelve German works.

In Austria the basic process was first tried at the Witkowitz Works in 1879, and this was rapidly followed by trials at the Works at Kladno and at Teplitz. In Belgium work was started by the Angleur Steelworks early in 1881 and the results proved in every way satisfactory. In France experiments had been carried out at Creusot in 1879 and at the Montluçon Works, and in 1880 Messrs. de Wendel started to erect Bessemer plants at Hayange and Jouef. In America, although one or two works started operating the basic Bessemer process, it was used only to a very limited extent, owing to the relative scarcity of high-phosphoric ores. In the late 'eighties the first basic open-hearth plant began to operate in the United States; in 1896 the total output of basic open-hearth steel was under 800,000 tons per annum, but by 1926 it was nearly 40,000,000 and last year (1936) the output was over 43,000,000 tons.

In England at the end of 1880, apart from the experiments at Messrs. Bolckow, Vaughan's and Messrs. Brown, Bayley and Dixon's Works, no other existing steelworks had tried the process, but Messrs. Bolckow, Vaughan & Co. had arranged to erect a new plant to operate the process at their works. In July, 1881, the North Eastern Steel Co., Ltd., was incorporated, and erected a new works specially designed to operate the basic Bessemer process at Middlesbrough. In June, 1881, Mr. (afterwards Sir) Alfred Hickman made arrangements with the Patent Shaft & Axle Co., Ltd., at Wednesbury for an experimental trial of 70 to 80 tons of common Staffordshire cinder iron containing from 3·0 to 4·0% of phosphorus in one of their old disused Bessemer converters, and as the result of this trial the Staffordshire Steel & Ingot Co., Ltd., was formed, and the erection of works at Bilston adjoining the blast-furnaces of Sir Alfred Hickman was commenced in 1882.

In 1880, 10,000 tons of basic steel were made in England, compared with 40,000 tons in all countries on the Continent, and this ratio of about one quarter of the total Continental output was maintained until 1890, when the output of basic Bessemer steel on the Continent was 2,021,000 tons, compared with approximately 500,000 tons in Great Britain. In 1890 the German output was approximately 1,500,000 tons.

The North Eastern Steel Co., Ltd., at Middlesbrough began to operate early in 1883 and the Staffordshire Steel & Ingot Iron Co., Ltd., started early in 1884, the former working with pig iron produced from Cleveland ores with small additions of tap cinder, and

the latter working with what was known as "cinder" iron, *i.e.*, iron made from about 80% of tap cinder and containing from 3·0 to 3·5% of phosphorus. Later on, basic Bessemer plants were started at Glasgow and Glengarnock.

British Ironmasters have been criticised for their lack of enterprise in not developing the basic Bessemer process more rapidly in this country, and comparisons are frequently made with the rapid progress which was made on the Continent, and especially in Germany.

No doubt vested interests, prejudice against a new process, and general conservatism did, as in all human affairs, retard development, but the conditions in this country and Germany differed in many important respects.

In Germany many of the most important existing works were situated in close proximity to their large phosphoric ore deposits, but in England, with the exception of those in the Sheffield district, all our large steelworks were situated on the coast, as our steel industry depended very largely upon our export trade; apart from the works in the Middlesbrough district none were in close proximity to our large phosphoric ore deposits.

The works in the Cumberland district had their rich 50% hematite iron ore deposits at their door, and at that time could make acid Bessemer steel from this local ore cheaper than by transporting ore or pig iron from Northamptonshire, Lincolnshire, or Cleveland. The other large works in South Wales and elsewhere, were, it is true, by this time largely dependent upon imported ore, but most of them had acquired an interest in high-grade ore deposits in Spain, and, under the cheap conditions of mining and transport then prevailing, could produce acid Bessemer steel cheaper than they could basic Bessemer steel from ore or pig iron from the Midlands, Lincolnshire, or Middlesbrough. Even from the local Cleveland stone in the Middlesbrough district it was by no means so easy to produce a satisfactory basic pig iron as from the ore of Lorraine and Luxemburg. This was recognised in Germany, and Herr Massenez, writing in *Stahl und Eisen* in 1903, said "The reason for the slow development of the basic Bessemer process in England was that the phosphoric ores, especially the Cleveland ores, with their high content of silica, alumina, and sulphur, and relatively low phosphorus, were less suitable than most of the phosphoric ores in Germany."

After the early experiments in Bolckow, Vaughan & Co.'s works it was found that a pig iron sufficiently high in phosphorus for regular and economic working could not be produced from Cleveland ore alone, and the phosphorus had to be increased by the addition of some phosphoric material to the blast-furnace burden. At that time there were large accumulations of tap cinder from the puddling furnaces available at a very low price, and small additions of this enabled a satisfactory pig iron to be produced.

In Staffordshire when the works at Bilston started they relied

mainly on tap cinder as their iron ore, which at that time could be obtained at about 25*s*. 0*d*. per boat load at the puddling works, and in some cases for the cost of fetching. From 50% to 80% of this tap cinder was used in the furnace burden, the balance being principally Northamptonshire ore, Oxfordshire ore, and a little local clay band. Gradually, as the puddling furnaces ceased to operate, the stocks of tap cinder became unobtainable, or obtainable in such small quantities and at such a high price that it no longer paid to use it. The same occurred at Middlesbrough, where, although the percentage used in the blast-furnace was very small compared with Staffordshire, the available supplies of tap cinder were much smaller, and one of the difficulties experienced by the North Eastern Steel Co., before they finally stopped operating, was the obtaining of a cheap phosphoric material to increase the phosphorus in their pig iron to the required extent.

When the basic process was introduced, the acid open-hearth was just beginning to be a serious competitor to the acid Bessemer, and the tendency in all countries, especially since the development of the basic open-hearth process with large tilting furnaces, has been for the open-hearth gradually to supersede the Bessemer, in both basic and acid practice.

There have been two main reasons for this:

(1) The wide distribution of ores containing too much phosphorus for the acid process, and too little for the basic Bessemer, but which produce a pig iron particularly suitable for basic open-hearth practice. This cause has been most noticeable in the United States, where there are large ore deposits widely distributed which produce a pig iron with from 0·2% to 0·5% of phosphorus.

(2) The greater control of the open-hearth process, especially during the finishing stages, when it can be readily sampled and any required adjustments made. Rightly or wrongly, but largely for the latter reason, the basic open-hearth process is considered by most engineers and many metallurgists to give a more regular and reliable product, especially when steels of varying carbon content are specified to meet different engineering requirements.

The general tendency therefore in recent years has been for the basic open-hearth process to supplant the basic Bessemer in all steel-producing countries of the world. In America, out of a total output of 47,706,000 tons per annum, 43,000,000 tons were last year made in the basic open-hearth furnace, and even in Germany the output of basic open-hearth steel was 8,600,000 tons, compared with 6,880,000 tons made by the basic Bessemer process.

At the same time it has been fully recognised for many years by steel metallurgists that for certain purposes, dead soft basic Bessemer steel gives better results than open-hearth steel, and this

is especially the case for such purposes as tube strip, where good welding properties are of the first importance. Certain tinplate manufacturers also prefer basic Bessemer steel, claiming that it is easier to roll and generally gives more satisfactory results.

Largely to meet the requirements of their tube works, Messrs. Stewarts & Lloyds, Ltd., have recently erected a modern basic Bessemer plant at Corby in Northamptonshire. They had their first blow on the 27th December, 1934, and are now producing about 325,000 tons of basic Bessemer steel per annum from Northamptonshire ore with most satisfactory results.

In the early days of basic Bessemer practice, to obtain the best results and prevent cold heats, it was found necessary to have not less than 2·0% of phosphorus in the pig iron, but in modern practice with large converters, large metal mixers and every facility for very rapid working, pig iron containing from 1·7% to 1·8% of phosphorus gives quite satisfactory results. This has made the utilisation of Northamptonshire ores easier, as a very small addition of phosphoric material to the blast-furnace burden will enable a pig iron with 1·7% to be produced from Northamptonshire ore, and the extra phosphorus required can be supplied by using low-grade basic slag produced in open-hearth furnaces containing too little phosphoric acid for use as a manure.

The re-introduction of the basic Bessemer process to Great Britain with the utilisation of our home ores is a most important development welcomed by all interested in iron and steel manufacture, both for technical and economic reasons.

In 1879 the Bessemer process was the main process for producing steel for rails, sections, plates, &c., the acid open-hearth being largely confined to the production of steels for special purposes. As was to be expected under the circumstances, the basic process was first tried in the Bessemer converter, but had the position been reversed there is little doubt that Thomas would have carried out his first experiments in the open-hearth furnace, as the essential principles on which dephosphorisation depends, *i.e.*, basic lining and basic conditions, apply equally to both. The first reference to the basic open-hearth of which the author is aware was made by Sidney Thomas in the discussion on Herr Richard Pink's paper and Messrs. Holland and Cooper's paper at the May Meeting in 1880, when he referred to promising results obtained with an open-hearth furnace at the Creusot Works, but it is believed that some experiments were carried out somewhat earlier than this at Alexandrowsky in Russia.

The first basic open-hearth furnace which the author saw operating was a 7-ton furnace at the works of the Patent Shaft & Axle Co., Ltd., at Wednesbury about 1884.

In 1886 a small 7-ton furnace was erected at the Staffordshire Steel & Ingot Iron Co.'s works at Bilston, and after the usual troubles excellent steel was made from pig iron containing over 3·0% of phosphorus.

Gradually furnaces were erected in different parts of the country, but the first open-hearth plant especially designed to operate the basic process was that designed and erected by the late John H. Darby at Brymbo in 1884, followed afterwards by the Frodingham plant started under the management of the late Mr. Mannaberg.

The three great steel processes, the Bessemer, the Siemens open-hearth, and the Thomas-Gilchrist basic process, have this distinction, that, notwithstanding the immense strides that have been made in production, these processes are fundamentally the same as when first introduced by the inventors. While this is true, it is equally true that the present development of the steel industry has only been made possible by the all-round improvements in engineering design and construction, and modifications in practical operation.

The great increase in blast-furnace output is due almost entirely to modification in construction and in the equipment for handling raw materials and the molten metal. The great improvement in the design of the modern converter, with its increased size, movable bottom section, &c., and the development of the modern tilting furnace, together with the general improvement in equipment of both Bessemer and open-hearth plants for the rapid charging of raw materials, and for casting the finished steel, have enabled these plants to deal with the large output of molten metal from the blast-furnace. These have made possible the increase in capacity of the converter from 8 tons to 25–35 tons, and an increase in size in the open-hearth from 15 tons to 300 tons. By the improvement in layout and general design and equipment of the mills, our engineers have enabled the ingots to be dealt with as rapidly as produced.

On the operating side, the introduction of the metal mixer, whether used only as a storage for metal or, as first operated by Herr Massenez, as an active mixer for desiliconising and desulphurising, has been of the greatest service. The first mixer was erected at the Edgar Thompson Works in America by Captain R. W. Jones, and without any knowledge of this a similar mixer was erected by Gustav Hilgenstock at the Hoerde Works within a very few months. The introduction of the Talbot process, with its large outputs, and the invention of the Darby direct carburising process, now used all over the world, have had the greatest influence in the development of the basic open-hearth process. The duplex process, the Bertrand-Thiel and the Hoesch processes, have also had their influence in assisting its development. The Saniter desulphurising process, by the use of chloride of calcium, leading afterwards to the use of fluorspar, has also been of great service to the industry, while special attention to detail has in various ways increased production, improved the quality of the finished product, and reduced costs. The increase in size and efficiency of the mechanical gas producer and the use of a mixture of coke-oven and blast-furnace gas for open-hearth furnaces have greatly decreased fuel consumption. In the early days 80 blows from one lining of a Bessemer converter was considered very good,

but to-day there are records of as many as 350 blows from one converter lining; in open-hearth practice the life of the basic hearth has greatly increased, owing to improved methods of lining the furnace and to improvements in refractory materials.

Basic Slag.

From the very first, Sidney Thomas realised the great potential value of basic slag as a by-product of his steel process, and in 1878 he wrote to Gilchrist that unless it was absolutely necessary he did not want anyone to know that he was contemplating its use for agricultural purposes, as it might be a very valuable asset later.

The general opinion in 1880 amongst agricultural chemists appears to have been that the phosphoric acid which was present as an insoluble phosphate would be useless as a fertiliser if the slag were used direct as a manure, and that it would be necessary to submit the slag to some chemical treatment to obtain a soluble phosphate; this problem Thomas set himself to solve. From 1882 to 1884 he had five chemists working on his instructions, but he evidently was not satisfied with the opinion expressed by agriculturists, that the slag could not be used direct on the land, and immediately slag was available from the North Eastern Steel Co. he had samples sent to Professor Wrightson and Dr. Munro to be crushed and used on experimental plots. The first results were not very successful, probably owing to the slag not being ground sufficiently fine, and it was not until after Thomas' death that the above-mentioned gentlemen obtained satisfactory results in Britain.

Experiments with finely ground slag were started earlier in Germany than in England, and to Germany belongs the credit of demonstrating that, provided that the slag was sufficiently finely ground, the phosphoric acid present was readily assimilated by plants. The early experiments were carried out by Professor Wagner of Darmstadt, and experiments were started about the same time on a larger scale by G. Hoyerman (Peine, Hanover) and showed conclusively that it was only necessary to grind the slag finely to make the phosphoric acid available as a plant food.

The results of these experiments were not known for a considerable time outside Germany, and it was only just before his death in February, 1885, that Thomas obtained particulars.

At once grinding plants began to be erected in connection with the main basic Bessemer works in all countries.

In 1913 the production of Bessemer slag in Europe used for agricultural purposes was approximately 4,500,000 tons, and last year it was about the same.

For some years Thomas had been working at very high pressure, and in May, 1879, he resigned his position at the Thames Police Court and devoted his whole time to business negotiations in connection with his process. The relief from strenuous work was, however, not so great as had been expected, as in 1880 his business

necessitated constant travelling, and his diary is one continuous record of journeys night and day to and from the Continent. Under this stress his health, never robust, began to suffer, but there was so much to be done that he found it impossible to take a badly needed rest. In March, 1881, he went to the United States to negotiate respecting his patent rights. There he met all the leaders of the steel industry and many other well-known Americans, and received the greatest hospitality. On his return the state of his health was so serious that he had to take a rest, but was unable to take that complete rest which after events showed was essential. In the following year his medical advisers insisted upon his going to South Africa for the winter. The next nine months were spent travelling in search of health, during which he visited Australia and India. He returned to England in July, 1883, but his health was so unsatisfactory that he was advised to leave at once for Algeria. He remained there until July, 1884, during which time he had his technical assistant Mr. Twynam with him working in an improvised laboratory on the slag question. No real improvement in health resulted from his residence in Algeria, and in July, 1884, he returned to Paris to consult a specialist of high repute. At first he seemed to benefit under the new treatment, but this improvement was not maintained, and he died on the 1st February, 1885, just before he reached the age of 35.

The direct and indirect effect of the development of the Thomas-Gilchrist process on the steel industry and the various other industries whose success and progress depend upon cheap steel, and on the progress of the world as a whole, it is practically impossible to estimate. Directly, the facts are : Approximately 90% of the world's output, or about 90,000,000 tons, of steel are to-day produced by the basic process. This involves the mining of probably not less than 250,000,000 tons of phosphoric ore per annum, which could not have been used for steelmaking without the invention of the dephosphorising process, and to this must be added the millions of tons of coal and limestone required yearly for the production of the finished steel. The total production of basic Bessemer slag in Europe, averaging about 16% of phosphoric acid, produced since the introduction of the basic process has not been less than 140,000,000 tons and probably has exceeded this, and has contained about 22,000,000 tons of phosphoric acid, which has been returned to the land to increase its productivity.

If the value of a man's work is to be judged by the wealth he creates for the community, taking the above facts alone, few inventors can show such a record. No one can say what have been the indirect effects of the development of the Thomas-Gilchrist process, but it is certain that without this invention, or some other process, which enabled the phosphoric ore deposits to be utilised for steel manufacture, the cost of steel would have been so increased that the great developments in railway, shipbuilding and general engineer-

ing during the last sixty years would have been to a very large extent impossible. The cost of transport by sea and land, on which the price of commodities so largely depends, would have been so increased that the world's progress would have been restricted to an extent which it is difficult to realise, and the general conditions of the world would have been very different from what they are to-day.

The untimely death of Thomas at the early age of 35 deprived the world of a man who, had he lived, would, with his great ability, energy, capacity for work, and strong personality, have achieved still greater things. At the time of his death his process was only in its infancy, and its full potentialities were not realised even by those with an intimate knowledge of the industry. This Institute was able to recognise his great services by awarding him the Bessemer Gold Medal in 1883, but he was then too ill to attend and receive it personally.

In conclusion, the author would like to add a few words about Thomas as a man. Although science and its application to industry were what appealed most strongly to him, he was also a man of wide culture and took the keenest interest in art and literature, and in the general social questions of the day. He had the highest ideals, and his whole life was governed by a sense of true citizenship dominated by great courage, which, even when failing health made life a burden, enabled him to continue his experimental work up to the very end. His ideals were perhaps more clearly indicated by his will than by anything else. After making a modest provision for his mother and sister, he left the residue of his property to his sister, free from all restrictions, to be used at her discretion for " the *benefit of workers in the widest sense.*" This has been regarded as a sacred trust, and his sister has devoted a large part of her life to administrating his estate in the way in which her brother would have wished.

We are very proud of the fact that the world is indebted to the genius of an Englishman, supported by the enterprise of our great industrialists, for the technical and commercial development of this great steel process.

The author wishes to express his indebtedness to Dr. Otto Petersen of Düsseldorf, Mr. A. Kipgen of Luxemburg and Mr. J. C. Chantraine of Belgium, for valuable data supplied concerning the production of basic slag in their respective countries and other information, and particularly to thank Mrs. Percy Thompson for permitting him to see many of the original letters written by Sidney Thomas and for supplying other valuable details. The author also thanks Messrs. Dorman, Long & Co., Ltd., for their kind loan of the blocks used to reproduce the portraits accompanying this paper.

Appendix.

Below are Tables giving statistics of the production of steel by the basic Bessemer process and the basic open-hearth process in the United States of America, Germany, France, and the United Kingdom for those years for which figures are available. Unfortunately other countries, including Belgium, do not give under separate headings the production by the different processes, but only the total production of basic steel, or in some cases the total production of steel by all processes. The following is approximately the total production of basic steel in all countries for the year 1936 :

	U.S.A.	Germany.	France.	United Kingdom.	Other Countries, Basic Bessemer and Open-Hearth Steel. Approx.	Total World Production, Basic Bessemer and Open-Hearth Steel. Approx.
Basic open-hearth. Tons . . .	43,114,000	8,800,000	2,000,000	8,260,000	22,000,000	...
Basic Bessemer. Tons . . .	...	7,000,000	4,500,000	324,000		
Total basic steel. Tons . .	43,114,000	15,800,000	6,500,000	8,584,000	22,000,000	95,998,000

Table I.—*Steel Production in the United States of America.*

Year.	Basic Open-Hearth. Tons.	Total Steel Production, including other Processes and Castings. Tons.	Year.	Basic Open-Hearth. Tons.	Total Steel Production, including other Processes and Castings. Tons.
1896	776,256	5,281,689	1917	32,087,507	45,060,607
1897	1,056,043	7,156,957	1918	32,476,571	44,462,432
1898	1,569,412	8,932,857	1919	25,719,312	34,671,232
1899	2,080,426	10,639,857	1920	31,375,723	42,132,934
1900	2,545,091	10,188,329	1921	15,082,564	19,783,797
1901	3,618,993	13,473,595	1922	28,387,171	35,602,926
1902	4,496,533	14,947,250	1923	34,665,021	44,943,696
1903	4,734,913	14,534,978	1924	30,719,523	37,931,939
1904	5,106,367	13,859,887	1925	37,087,342	45,393,524
1905	7,815,728	20,023,947	1926	39,653,315	48,293,765
1906	9,658,760	23,398,136	1927	37,144,268	44,935,185
1907	10,279,315	23,362,594	1928	43,200,483	51,544,180
1908	7,140,425	14,023,247	1929	47,232,419	56,433,473
1909	13,417,472	23,955,021	1930	34,268,316	40,699,483
1910	15,292,329	26,094,919	1931	22,130,398	25,945,501
1911	14,685,932	23,676,106	1932	11,742,682	13,681,162
1912	19,641,502	31,251,303	1933	20,057,146	23,232,347
1913	20,344,626	31,300,874	1934	23,256,417	26,055,289
1914	16,271,129	23,513,030	1935	30,361,237	34,092,594
1915	22,308,725	32,151,036	1936	43,114,826	47,767,856
1916	29,616,658	42,773,680			

TABLE II.—*Steel Production in Germany (including Luxemburg).*

Year.	Bessemer.		Open-Hearth.		Total Production, including other Processes and Castings. Tons.
	Acid. Tons.	Basic. Tons.	Acid. Tons.	Basic. Tons.	
1880	678,953	18,180	35,820		732,953
1881	509,400	200,000	188,100		897,500
1882	687,324	235,132	152,544		1,075,000
1883	396,745	328,909	326,344		1,051,998
1884	388,876	440,000	313,124		1,142,000
1885	378,814	548,212	275,974		1,203,000
1886	341,142	784,212	210,646		1,336,000
1887	345,672	1,167,702	224,626		1,738,000
1888	316,702	1,137,632	408,666		1,863,000
1889	324,392	1,305,887	465,221		2,095,500
1890	350,862	1,493,157	387,981		2,232,000
1891	307,357	1,779,779	475,864		2,563,000
1892	251,055	2,013,484	491,461		2,756,000
1893	280,992	2,344,754	537,254		3,163,000
1894	327,700	2,342,161	1,078,600		3,748,461
1895	315,600	2,520,396	1,189,400		4,025,396
1896	351,500	3,004,615	1,477,807		4,833,922
1897	391,850	3,234,214	1,404,423		5,030,487
1898	383,232	3,606,734	1,459,159		5,449,125
1899	371,620	3,973,225	1,693,825		6,038,670
1900	223,063	4,141,587	147,800	1,997,765	6,645,869
1901	299,816	3,975,070	125,590	1,886,536	6,394,222
1902	341,885	4,888,054	129,724	2,304,495	7,780,682
1903	435,327	5,473,195	132,693	2,628,544	8,801,515
1904	423,742	5,525,429	130,546	2,697,760	8,930,291
1905	424,196	6,203,706	165,930	3,086,590	10,066,553
1906	407,688	6,772,804	230,668	3,534,612	11,135,085
1907	387,120	7,212,454	212,620	4,039,940	12,063,632
1908	374,100	6,510,754	146,768	3,854,155	11,186,379
1909	151,148	7,517,451	228,798	3,844,139	12,049,834
1910	171,108	8,030,571	140,189	4,973,569	13,698,638
1911	187,359	8,640,164	281,877	5,501,147	15,019,333
1912	187,179	9,794,300	194,924	6,650,565	17,301,998
1913	155,138	10,629,697	283,480	7,330,424	18,935,089
1914	100,617	8,143,619	274,321	5,946,215	14,946,212
1915	164,570	6,529,285	248,649	5,423,364	13,258,054
1916	175,109	7,653,990	276,909	6,579,892	16,182,520
1917	173,430	7,294,899	217,783	7,056,690	16,587,360
1918	148,980	6,410,751	184,490	6,593,416	14,979,505
1919	51,174	2,904,457	60,534	4,415,753	7,847,356
1920	45,102	3,219,624	74,568	5,540,987	9,277,882
1921	20,371	3,536,007	105,449	5,945,914	9,996,538
1922	46,624	4,169,517	142,979	6,891,305	11,714,302
1923	6,626	1,978,001	65,753	3,974,986	6,305,250
1924	26,848	3,989,670	134,259	5,364,353	9,835,255
1925	22,448	5,110,646	149,293	6,475,223	12,194,501
1926	133	5,452,223	116,126	6,484,467	12,341,636
1927	354	6,903,656	185,150	8,720,005	16,310,682
1928	28	6,548,027	149,377	7,360,076	14,517,103
1929	...	7,394,458	143,925	8,223,870	16,246,078
1930	...	5,136,527	106,162	5,936,168	11,538,624
1931	15	3,222,302	77,859	4,705,084	8,291,634
1932	3	1,817,060	45,258	3,634,118	5,770,105
1933	...	2,625,616	57,535	4,595,129	7,611,789
1934	...	4,413,401	117,512	6,886,986	11,916,426
1935	...	6,884,988	175,546	8,651,818	16,446,673

The production of Lorraine and Luxemburg is excluded from 1919.
The production of Upper Silesia is excluded from July, 1922.
The production of the Saar District is excluded from 1921 to 1934, but is included in 1935.

TABLE III.—*Steel Production in France.*

Year.	Bessemer.		Open-Hearth, Basic. Tons.	Total Steel Production, including other Processes and Castings. Tons.
	Acid. Tons.	Basic ("Thomas"). Tons.		
1896	726,463		454,280	1,180,743
1897	802,326		522,887	1,325,213
1898	883,601		550,116	1,433,717
1899	879,181		619,845	1,499,026
1900	919,283		645,881	1,565,164
1901	816,677		608,674	1,425,351
1902	959,097		609,206	1,568,303
1903	1,161,954		677,674	1,839,628
1904	130,294	1,225,015	732,165	2,095,609
1905	132,896	1,350,814	756,574	2,255,223
1906	107,978	1,494,667	833,677	2,451,509
1907	78,771	1,669,757	1,001,463	2,766,773
1908	89,393	1,636,536	978,531	2,723,046
1909	103,238	1,852,233	1,059,235	3,039,046
1910	105,582	2,136,558	1,137,397	3,413,304
1911	110,923	2,393,909	1,303,652	3,847,052
1912	124,663	2,812,780	1,452,627	4,428,514
1913 *	252,704	2,806,475	1,582,478	4,686,866
1914	74,767	1,505,225	1,040,079	2,655,854
1915	29,827	59,459	944,836	1,087,700
1916	583,323		1,290,833	1,951,892
1917	638,780		1,498,353	2,231,651
1918	394,637		1,312,625	1,807,931
1919 †	48,682	1,012,916	1,065,166	2,186,260
1920	60,188	1,656,972	1,255,120	3,050,396
1921	45,094	1,779,860	1,243,216	3,102,170
1922	43,612	2,888,330	1,554,127	4,534,492
1923	70,957	3,007,828	1,968,148	5,109,517
1924	91,709	4,501,167	2,230,247	6,900,310
1925	78,903	5,175,815	2,103,469	7,446,463
1926	60,699	5,812,264	2,458,296	8,430,002
1927	70,559	5,880,532	2,252,492 ‡	8,306,256
1928	80,588	6,586,214	2,688,648	9,499,528
1929	98,811	6,679,503	2,752,837	9,698,946
1930	116,910	6,569,219	2,596,795	9,446,561
1931	85,964	5,486,795	2,084,891	7,821,627
1932	55,404	3,785,512	1,639,241	5,640,034
1933	48,069	4,429,903	1,864,613	6,530,900
1934	42,691	4,075,614	1,848,973	6,174,174
1935	46,218	4,004,248	1,966,190	6,276,776
1936	41,000	4,387,000	1,997,000	6,708,000

* From 1913 the figures include castings.

† From 1919 includes Alsace-Lorraine.

‡ From 1927 includes acid open-hearth; in 1935 this amounted to 24,655 tons.

TABLE IV.—*Steel Production in the United Kingdom.*

Year.	Bessemer Ingots.		Open-Hearth Ingots.		Total Steel Produced, including other Processes and Castings. Tons.
	Acid. Tons.	Basic. Tons.	Acid. Tons.	Basic. Tons.	
1880	1,044,020		250,913		1,294,933
1881	1,440,122		337,882		1,778,004
1882	1,673,070		435,849		2,108,919
1883	1,552,843		455,342		2,008,185
1884	1,299,227		475,085		1,774,312
1885	1,303,676		583,710		1,887,386
1886	1,569,970		693,910		2,263,880
1887	2,063,689		980,764		3,044,453
1888	2,012,098		1,292,295		3,304,393
1889	1,719,292	422,211	1,429,169		3,570,672
1890	1,612,730	402,133	1,564,200		3,579,063
1891	1,306,229	335,776	1,514,538		3,156,543
1892	1,202,000	298,783	1,418,830		2,919,613
1893	1,230,992	262,362	1,456,309		2,949,663
1894	1,139,611	395,753	1,575,318		3,110,682
1895	1,093,675	441,550	1,724,737		3,259,962
1896	1,357,580	457,262	2,317,555		4,132,397
1897	1,374,339	509,816	2,602,006		4,486,161
1898	1,255,252	504,134	2,806,600		4,565,986
1899	1,307,696	517,378	3,030,251		4,855,325
1900	1,253,903	491,107	3,156,050		4,901,060
1901	1,115,985	490,628	2,946,614	351,177	4,904,404
1902	1,157,380	668,399	2,676,508	406,780	4,909,067
1903	1,316,915	593,103	2,613,274	510,809	5,034,101
1904	1,129,224	652,309	2,583,282	662,064	5,026,879
1905	1,396,233	577,977	3,042,834	795,238	5,812,282
1906	1,307,149	600,189	3,378,691	1,176,245	6,462,274
1907	1,280,315	578,944	3,384,780	1,278,709	6,522,748
1908	906,466	572,073	2,578,840	1,238,263	5,295,642
1909	1,111,942	622,178	2,763,158	1,385,250	5,881,628
1910	1,138,103	641,012	3,016,830	1,578,536	6,374,481
1911	887,767	573,373	3,131,118	1,869,354	6,461,612
1912	980,662	541,825	3,365,570	1,908,087	6,796,144
1913	1,048,772	551,929	3,811,382	2,251,793	7,663,876
1914	797,072	482,444	3,680,848	2,874,749	7,835,113
1915	821,408	479,816	4,090,752	2,958,968	8,550,015
1916	914,346	542,119	4,355,845	2,978,885	8,991,729
1917	916,348	584,816	4,545,196	3,355,571	9,716,544
1918	754,899	550,500	3,880,949	3,986,269	9,539,439
1919	493,000	296,200	2,960,000	3,934,800	7,894,000
1920	552,500	268,400	3,302,100	4,682,000	9,067,300
1921	184,500	54,000	1,136,900	2,214,100	3,703,400
1922	272,500	196,000	1,680,400	3,624,300	5,880,600
1923	357,800	137,500	2,515,700	5,278,100	8,481,800
1924	405,800	109,700	2,358,800	5,117,500	8,201,200
1925	447,200	28,300	1,968,600	4,744,000	7,385,400
1926	152,500	...	1,027,000	2,260,400	3,596,100
1927	445,200	...	2,519,100	5,920,900	9,097,100
1928	475,900	...	2,170,500	5,660,800	8,519,700
1929	527,600	100	2,403,800	6,480,200	9,636,200
1930	255,300	...	1,761,000	5,091,100	7,325,700
1931	113,000	...	1,155,100	3,777,400	5,202,600
1932	111,600	...	1,096,700	3,905,200	5,261,400
1933	189,400	...	1,523,700	5,132,200	7,024,000
1934	222,900	...	1,708,400	6,667,100	8,849,700
1935	199,200	223,800	1,812,000	7,346,500	9,858,700
1936	238,600	323,600	2,111,800	8,760,600	11,784,600

DISCUSSION.

Sir WILLIAM LARKE, K.B.E. (Vice-President, London), said a deep debt of gratitude was due to the author for his paper and for his tribute to one who had really made the modern steel industry possible. Personally, he always liked to think of Thomas's work as a great romance and as another example of the amateur making a discovery which was revolutionary. It was impossible to measure the effect of Thomas's discovery of the basic process on modern civilisation; the mind reeled in considering what would have been the present state of our civilisation had the basic process not been introduced.

One small instance of the enthusiasm with which Thomas was inspired, and to which the author had not referred, might be mentioned. That white-hot enthusiasm which caused Thomas to neglect all questions of physical fatigue and so on led him not once but two or three times actually to set fire to the bedroom in which he was making his preliminary experiments.

It was very appropriate that at the present Meeting a tribute should be paid to the past. There was a tendency to accept the gifts received from the past without a thought as to their significance for the present or as to the inspiration to be obtained from them in the future. The thanks of the Institute were due to the author for having placed so exhaustive and comprehensive an account of Thomas's great invention on its records.

Mr. J. R. SKINNER (Redcar) was called upon to speak, but it was stated on his behalf that he had now retired from business for a number of years, and did not feel able to take part in the discussion. He was, it was explained, a contemporary of Thomas, and did all the analyses in connection with the first experiments at the works of Bolckow, Vaughan & Co.

The PRESIDENT (Mr. Alfred Hutchinson) said he was sure the Members present would like to express their great pleasure at the presence of Mr. Skinner, who was a sort of historic monument to the development of the Thomas-Gilchrist basic process.

Mr. Harbord's paper was of great historical interest, and its importance at the present Meeting in Middlesbrough could hardly be over-estimated. The Members, he thought, would certainly like to express their appreciation of the author's presentation of such an interesting historical survey of the basic open-hearth and the basic Bessemer processes.

AUTHOR'S REPLY.

Mr. HARBORD, in reply, emphasised that the Thomas process was by no means a chance discovery, but was the result of years of study and was based on sound fundamental principles. He hoped that the success achieved by Sydney Thomas would be not only an encouragement but also an inspiration to the younger men to follow in his footsteps, and he (Mr. Harbord) would like them to realise that if success was to be attained it was essential for them first of all to gain a sound knowledge of the fundamental principles of chemistry and metallurgy and then apply these to practice, and they could then with confidence approach the steel manufacturer to assist in demonstrating the commercial possibilities of their proposals.

VARIATION IN THICKNESS OF THE TIN COATING OF TINPLATE, AND ITS EFFECT ON POROSITY.*

By W. E. HOARE, B.Sc. (Eng.) (London).

(Figs. 11 to 21 = Plates VI. and VII.)

Summary.

The general relation of tin coating thickness to porosity has been investigated. It is found that the number of pores per 100 sq. cm. falls from 8000 to 300 as the coating thickness is increased from 1 to 3 lb. per basis box, and falls more slowly from 300 to 2 as the coating thickness is further increased to 15 lb. per basis box. From a consideration of the shape of the tin-yield/porosity curve it is shown that local variation of the coating thickness tends to produce over-sheet increases of porosity.

"Bridging over" of potential sites of normal pores has been established, and the implications are commented upon. The theoretical findings of Chalmers with respect to the minimum pore size possible for any particular coating thickness have been confirmed.

The three orders in which the coating thickness varies are detailed and the corresponding porosity effects are discussed.

A new technique has been evolved, which enables a quick estimation to be made of the presence and type of macroscopic irregularities of coating thickness, and comments are made on the modes of formation of such irregularities. Possibly the most important finding in this respect is that a periodic variation of coating thickness occurs across the direction of tinning (*i.e.*, lines of convexity in the direction of tinning), this periodicity being coincident with that of the grease lines. These periodic variations have been termed *tin ridges*, and their existence has been confirmed by the application of several methods.

By receiving tin from other parts of the surface these ridges cause the tin yield at the corresponding troughs to fall to approximately 60% of the mean value.

The effect of cleaning on porosity has been examined.

The occurrence of porosity in the tin coating of tinplate has, in past years, been ascribed to numerous causes, and various suggestions have been made from time to time as to how it might be decreased or eliminated. From a consideration of this previous work it appears that porosity may be attributed to four major causes.

(i) The presence of non-reactive areas on the steel basis sheet as being inimical to the production of continuous coatings was

* Communication from the International Tin Research and Development Council Laboratories and the Sir John Cass Technical Institute, received June 8, 1937.

mentioned as early as 1797,[1] and many times subsequently.[2,3,4,5,6] There can be no doubt as to the general validity of this contention, the implications of which have led to improved methods for obtaining a chemically clean steel surface prior to tinning. It is reasonable to suppose that increased cleanliness of the steel basis sheet would result always in a decrease of normal porosity.

(ii) Porosity has been attributed to the evolution of hydrogen occluded previously in the pickling operations. This effect was investigated recently by Peter and Le Gal,[5] who found that it appeared from their experiments to be insignificant, though not necessarily absent.

(iii) The present author[3,4] has mentioned a further cause of porosity, *i.e.*, that occurring owing to conditions in the grease-pot. The discontinuities arising from this cause were termed *potential* pores, since, with this class of imperfection, registration under porosity tests is not necessarily obtained until after the sheet has been subjected to forming or bending operations.

(iv) The fourth major effect which has been mentioned as causing porosity is the abrasion, or partial removal of the coating, during the operations of cleaning and polishing. This effect has been noted in various places and was first estimated quantitatively by Hothersall and Prytherch.[7]

In spite of the guidance of these suggestions, it has not yet been found possible to effect any substantial reduction in the porosity of such tin coatings as are generally used in the canning industry. The present paper is an attempt to throw light on the relation between the tin coating thickness and the porosity, and to examine any implications of the relation.

It seems desirable to mention at the outset that the method of porosity testing adopted for the present paper was the hot-water test, preceded by cathodic degreasing.[8] This test was adopted for the following reasons.

First, this method of testing registers the smallest pores. The modified ferricyanide test does not always do this (particularly in the case of thin coatings), and this fact provides a reason why the latter test often gives much lower results than the former.* The jelly test was not used, since it was found difficult to obtain repeatable results. Secondly, the hot-water test has certain merits of convenience, inasmuch as a large number of specimens may be treated at once under exactly identical conditions, and that both faces of the specimens are tested at the same time.

When sampling was necessary the following procedure was

* Although the modified ferricyanide paper test cannot be considered to give absolute results with thin coatings, it is at the same time a useful inspection test. When the conditions of testing are well controlled, and a set of empirically chosen comparison standards is available, the test is convenient and reliable. Anodic sulphurisation tests (*see* Gire [9]) are essentially reactivity tests, and owing to attack of the tin coating would not be suitable for use in the present investigation.

adopted: for a box of 112 sheets, the second sheet from the top and the bottom and one sheet from approximately one-third and two-thirds of the way down were taken; for a box of 56 sheets, the second sheet from the top and bottom and one sheet halfway down approximately were taken. The individual sheets were usually cut up in the way illustrated in Fig. 1. The tin yield was

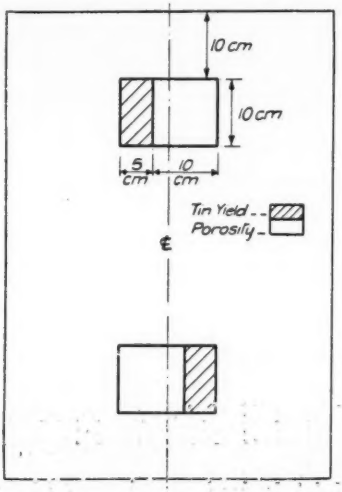


FIG. 1.—Method of Cutting Sampled Sheets.

estimated by Clarke's method.[10] Selective detinning was carried out with the solution used by Hothersall and Bradshaw.[11]

GENERAL RELATION OF TIN YIELD AND POROSITY.

The curves of Figs. 2 and 3, in which the porosity is plotted against the tin coating thickness, show the relation between these two variables, the results being consentient with those of previous work along these lines (*e.g.*, Peter and Le Gal,[5] Phillips and Leadbeater[14] and Rawdon[21]). The curve of Fig. 2 shows that the porosity falls rapidly as the tin yield is increased from 1 lb. to approximately 2½ lb. per basis box. As the tin yield is further increased the amount of the numerical decrease of porosity becomes much smaller, and the curve runs substantially asymptotic to the tin yield axis. In the curve of Fig. 3 the tin yield has been plotted on a linear axis and the porosity on a logarithmic axis. This method of plotting allows a more accurate placing of the points, particularly when the porosity falls below 100 per 100 sq. cm.

The apparent steady increase of scatter of the logarithmic curve as the porosity decreases is accounted for both by the considerable extension of the scale from the top to the bottom of the ordinate axis, and by the fact that the magnitude of the specimen tested has an increasing effect on the porosity figure obtained. Theoretically it would be more satisfactory to examine the inverse relation

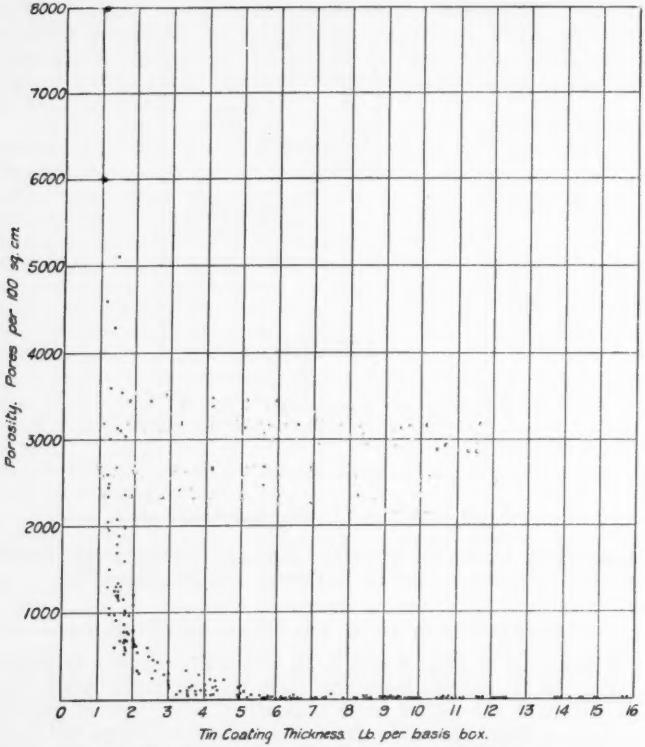


FIG. 2.—Relation of Porosity and Tin Coating Thickness.

of the *tin yield to the area containing a fixed number of pores.* In practice, of course, this method would suffer from the inconvenience of requiring tests on very large areas. The general trend of the curve is, however, sufficiently obvious.

It is apparent that the curves have an immediate practical function, in that they may be used to determine limits above which porosity values should not lie. The relation is sufficiently

well delineated to indicate that a porosity value obtained by the hot-water test on a series of correctly sampled specimens, which is found to be above the upper limits of the curve, could be justly considered as being below standard.

Consideration of the shape of the curves of Figs. 2 and 3 leads to the conclusion that local variations of coating thickness would tend to produce increased porosity even if the over-sheet coating thickness remained at the same figure.

Thus, abstracting average figures from the curve of Fig. 3, it

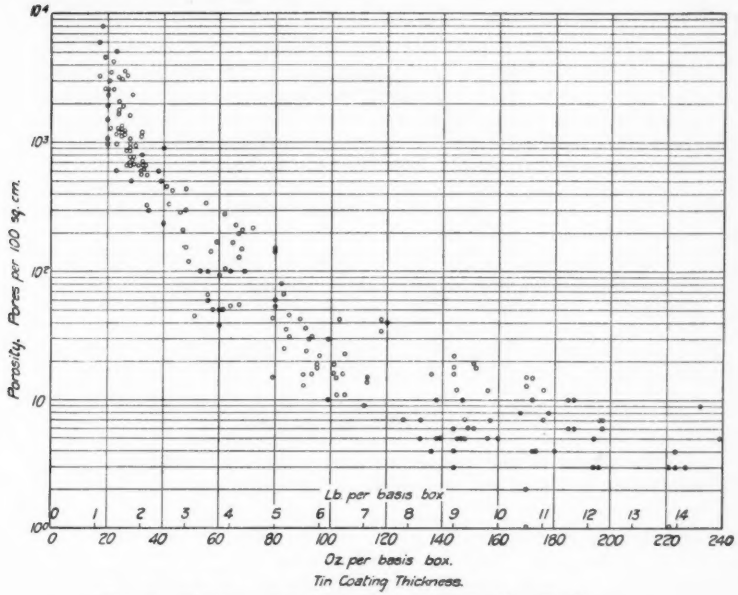


FIG. 3.—Relation of Log Porosity to Tin Coating Thickness.

will be seen that a tin yield of 2 lb. per basis box is associated with a porosity of 750 per 100 sq. cm. If, however, on a specimen 1 sq. dm. in area, one half has for some reason fallen to $1\frac{1}{2}$ lb. per basis box, with a consequent increase in the case of the other half to $2\frac{1}{2}$ lb. per basis box, then the total porosity will be increased to 1150 pores per 100 sq. cm.:

Mean porosity of $1\frac{1}{2}$-lb. per basis box tinplate	= 1800 per 100 sq. cm.
" " $2\frac{1}{2}$-lb. " " "	= 500 " "
Total on 200 sq. cm.	= 2300
Net porosity per 100 sq. cm.	= 1150 (*cf.* 750 per 100 sq. cm. originally).

This calculation holds good for any up and down variations however small, and shows that a local decrease of the coating thickness will, in addition to producing an associated local increase of porosity, also produce a total over-sheet increase in spite of local decreases formed in other places.

Variation of Tin Yield.

Theoretical.—Fig. 4 is a diagrammatic half-section of the top pair of rolls in the grease pot. The shaded areas represent liquid tin.

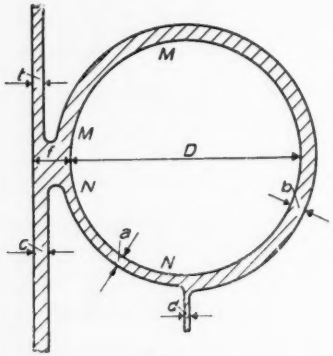


Fig. 4.

The action of the grease-pot rolls takes off a thickness of tin equivalent to $c - t$, and since with stable conditions

$$b + t = a + c,$$

and therefore

$$c - t = b - a,$$

the grease-pot rolls' action is capable of reducing the tin yield by an amount which is equal to the difference between the amount that the roll carries on its progression MM and the amount that it carries on its progression NN.

(1) This explains the action of grease-pot brushes. A brush placed at the bottom of the roll increases d, a dimension corresponding to the amount of tin draining off the roller, and therefore reduces a. Through the effect of decreasing f, $c - t$ is increased and the tin yield is decreased.

(2) If c increases steadily as the sheet passes through, owing to the sub-nip being fed by tin pushed back by the rolls, two effects will arise: d will increase and/or f will increase. In the event of the increase of d being insufficient to take care of the total amount

of tin being pushed back, f must increase. $b + t$ will therefore increase, and since the ratio b/t will be nearly constant, the tin yield will undergo a small progressive increase towards the list end.

(3) The amount carried through the nip f depends on viscous and gravitational forces. Viscosity tends to carry tin up to and through the nip; gravity tends to oppose this. Therefore if the *speed* increases, with a resultant increase of the viscosity forces, more tin will pass through f.

General.—Unless the nip is fed with tin, which is outside the scope of the argument,

$$f = b + t,$$

and therefore if f is constant then t is constant (*see* above). It therefore appears that f itself must be varied by factors other than the loading on the rollers, these factors being the amounts of liquid tin available from c and a. It is only by the ability of these factors to alter f (either unintentionally or deliberately) that they cause any variations of tin coating thickness. It should be remembered that effects such as scruff bands (*see* below) are caused by conditions altering momentarily the loading on the rolls.

It is therefore possible to conclude that if the grease-pot rollers were capable of being correctly cambered, maintained true, and kept dead in position, then with uniform steel substance the tin yield could be varied at will by adjusting f only. The mechanism of a tinning machine and variations of substance do not allow of this accuracy (but improvements are being made). Other devices, *i.e.*, grease-pot brushes, and spring loading of the rolls, must therefore be employed.

Orders of Variation.

The thickness of the tin coating on tinplate varies generally in three orders:

(1) The variation from sheet to sheet in the box.
(2) The variation over individual sheets on a large scale.
(3) Macroscopic variations over individual specimens (potential and normal pores, grease marks, ripples, &c.).

(1) *Variations from Sheet to Sheet in Box.*

This type of variation occurs generally, and some of the factors causing it have been investigated by Idris Williams.[12] Roughly speaking, these variations may be expected to be of the order of 20% each way on the mean value, but the extent varies considerably from box to box. Variations of porosity are always associated with this type of variation of tin yield.

(2) *Variations over Individual Sheets on a Large Scale.*

Variations of this kind have been found in the following directions:

(*a*) In the case of heavily-coated sheets the back end always appears to have a thicker coating than the front end. In Table I. a summary is given of the tin yield and porosity figures on five boxes of charcoal tinplate, all manufactured by the same procedure. It will be seen that the average tin yields for list-end specimens

TABLE I.—*Tin Yield and Porosity Figures for Five Boxes of Charcoal Tinplate (all made by the same Procedure).*

Mark.	Tin Yield (Mean of 3).	Porosity (Mean of 6).	Mean over Whole Box.	
			Tin Yield.	Porosity.
	Lb. Oz.		Lb. Oz.	
M	5 10	45		
MM	5 12	29	5 11	37
T	6 2	23		
TT	6 7	17	6 4½	20
N	8 11	10		
NN	9 3	10	8 15	10
U	9 5	6		
UU	10 7	4	9 14	5
*K*2	12 4	7		
*KK*2	14 3	3 (2·6)	13 3½	5 (4·8)

(double-letter marks) are in every case greater than those for front-end specimens. The associated porosity varies also in the correct direction, except in the case of tinplate *N* where the figure is the same. Theoretical reasons for this increase of coating thickness have been discussed above. It has been shown by Chalmers[15] that gravitational draining of the liquid tin is too slow for this factor to be significant as a cause of the increase.

For comparison with the curve of Fig. 2, the mean results obtained from Table I. have been plotted in the curve of Fig. 5. It will be seen that the curve is of similar shape and the divergences are less. This would be expected, since arbitrary differences of manufacturing technique have been eliminated.

The increased coating thickness at the back end is not always noticed in tinplates having a tin yield of below approximately 2 lb. per basis box. In certain cases where the list end of the sheet has a dry appearance, the variation may be in the reverse direction, the list end having a lower coating thickness and a higher porosity. It is convenient to mention *inter alia* that when specimens are sampled indiscriminately from individual sheets, the porosity does not always correspond with an inverse function of the tin yield, this being due to the intrusion of other factors which may mask

the effect on any individual. Such conclusions are "mean" conclusions, and can only be established by extensive repetition of the experiment; for instance, the curves (Figs. 2 and 3) contain some 200 points. In cases where the coating thickness is well removed from the mean, however, the associated porosity will always be increased or decreased in the correct direction. (For example, in the case of a tinplate having a mean tin yield of 1 lb. 6 oz. per basis box the porosity was 1300 at a place exhibiting a coating thickness of 1 lb. 5 oz. and 8000 at a place exhibiting 1 lb. $2\frac{1}{2}$ oz.)

The fact that the increased yield at the back end does not generally appear on plates of coke grade may be explained by the fact that the speeds and pressures are high and grease-pot brushes are used, all of which factors tend to stabilise the conditions.

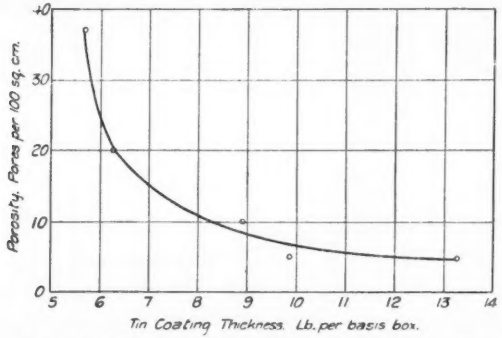


FIG. 5.—Relation of Porosity and Tin Coating Thickness in Tinplates all made by the same Process.

(*b*) Variation of tin yield from side to side of the sheet is caused by slack tinning rolls having less set at one side than the other. This can be demonstrated readily by running an under-width sheet through one side of the pot. Owing to the grease-pot rolls being wedged apart at one side only, the sheet will be found to have a higher tin yield on its outside than its inside edge. The effect of uneven thrust of the drive, causing a similar effect, has been discussed by Williams.[12]

(*c*) The author has not had the opportunity at present of investigating thoroughly the variation of porosity from face to face of individual sheets. One difficulty connected with the investigation of this factor is that with a box of tinplates obtained through the ordinary channels it is usually impossible to tell which is the bottom and which is the top face, except by begging the question and assuming that the face with the greater porosity is the bottom. The greater porosity of the bottom side has been mentioned by Schneider,[13]

and Phillips and Leadbeater [14] give results showing the extent of the difference. This is confirmed by the present author in the case of several specimens. It has been suggested previously that these differences are due to the difficulty of escape of flux reaction products from the under side of the sheet.

Effect of Varying the Tin Coating Thickness on Individual Specimens.

Considering further the variations occurring over individual sheets, the purpose of the following experiments was to determine whether the general relation of tin coating and porosity held for an individual specimen of tinplate. In order to vary the tin coating of a single sample conveniently, advantage was taken of the fact that when a specimen of tinplate is held vertically in a bath

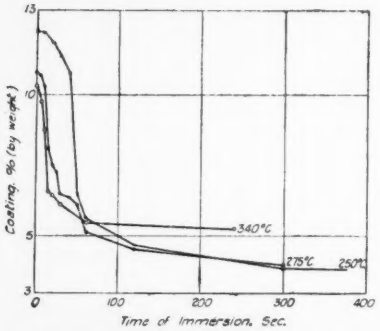


FIG. 6.—Rate of Stripping of Tin Coatings in Palm Oil.

of palm oil at a temperature above the melting point of tin, the coating is progressively removed by draining under gravity. Stripping curves of a tinplate carrying initially about 11 lb. of tin per basis box, and at three temperatures, are given in Fig. 6 (*see* Table II.). A further series of tests, in which the porosity was determined at successive steps in the stripping process, indicate that as the coating thickness is decreased, so the porosity increases. A typical case is shown in Fig. 7, in which the probable tin coating thickness has been estimated from Table II. (*see* Table III.).

These results indicate that possible normal pore sites may exist beneath a continuous coating, only becoming effective as the coating thickness is reduced. The mechanism by which this pore formation occurs has been discussed by Chalmers,[15] who states that a normal pore cannot be formed unless the diameter of the non-reactive area (*i.e.*, the potential site of a pore) is greater than 0·7 times the coating thickness. Since the mechanism involves the action of surface tension forces, it is obvious that it will only operate

when the coating is reduced by such means that the tin is in the liquid state. Chalmers' statement has since been confirmed by the present author. Some hundreds of normal pore sites, determined by the hot-water test, have been measured microscopically, and in every case the diameters of non-reactive areas at the base of the pores were found to be above the minimum dimensions appropriate to the particular tin yield. In some cases the non-reactive areas were

TABLE II.—*Stripping Data for a Tinplate carrying about* 11 *lb. of Tin per Basis Box.*

No.	Temp. °C.	Time. Sec.	Weight Difference. G.	Tin. %.
1	250	10	0·1765	12·20
2	,,	20	0·1689	11·83
3	,,	30	0·1666	11·40
4	,,	40	0·1587	10·80
5	,,	50	0·0938	6·48
6	,,	60	0·0819	5·62
7	,,	120	0·0650	4·63
8	,,	300	0·0560	3·83
9	,,	600	0·0510	3·56
10	340	5	0·1407	9·75
11	,,	10	0·1268	8·76
12	,,	15	0·0963	6·54
13	,,	20	0·0950	6·44
14	,,	30	0·0892	6·13
15	,,	60	0·0791	5·47
16	,,	240	0·0756	5·30
17	275	5	0·1624	10·71
18	,,	10	0·1556	10·30
19	,,	15	0·1240	8·08
20	,,	20	0·1141	7·46
21	,,	25	0·1101	7·27
22	,,	30	0·0989	6·52
23	,,	40	0·0943	6·39
24	,,	50	0·0881	6·08
25	,,	60	0·0737	5·10
26	,,	120	0·0668	4·53
27	,,	300	0·0600	3·90

irregular in shape. When this occurred, however, the minimum axis of the irregularity was always found to be well above the minimum dictated by Chalmers' findings.*

The microscopical appearance of specimens after the prolonged immersion in palm oil (*cf.* the conditions at the ends of the curves of Fig. 6) was found to be similar to that of the base of potential pores. It was felt, therefore, that it would be valuable to examine some of the properties of these specimens with a view to obtaining

* This does not refer to pores obviously caused by scratching or abrasion.

additional data on potential pores, and of their mode of breakdown under deformation.

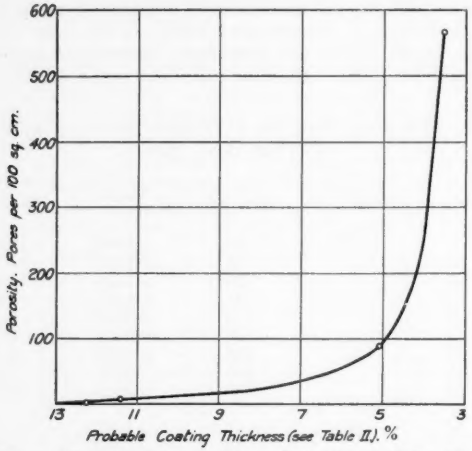


FIG. 7.—Increase of Porosity on Stripping in Palm Oil.

TABLE III.—*Variation of Tin Coating Thickness and Porosity during Stripping.*

Time.	Probable Coating Thickness. %.	Porosity.
0	12·25	3
30	11·40	7
90	5·10	89
600	3·56	567

The stable layer produced by stripping in palm oil appears to have different properties from the alloy layer produced by chemical stripping, which differences are found to be due to the capacity of the alloy layer to entangle a certain amount of free tin. The results summarised in Table IV. show that the amount of free tin entangled is reduced as the amount of compound decreases.

The porosity of such layers is considerably less than that of the alloy layer revealed by chemical detinning, previously estimated to be as high as 60,000 pores per 100 sq. cm.[11] Although the protection afforded to the steel basis sheet by this layer is relatively high initially, the results recorded in the last two columns of Table IV. show that it is sufficiently brittle to give negligible protection to the steel after the slight deformation occasioned by one

bend over a ½ in. dia. bar. The porosity of three specimens after deformation is shown in Fig. 11. The complete breakdown of protection at the centre of the specimens may be compared with the initial porosity at the undeformed edges.

TABLE IV.—*Effect of Deformation on the Layer "Compound plus Entangled Tin."*

Mark.	Free Tin. Oz. per basis box.	Alloy Tin. Oz. per basis box.	Total Tin. Oz. per basis box.	Porosity per sq. cm.	
				Before Bend.	After Bend.
K	19	24	43	20	Protection completely destroyed.†
J	5·4	17	22·4	30	
H	7·2	15	22·2	30	
R	1·9	11	12·9	50 *	

* Note in Fig. 11 (*a*) the peculiar type of breakdown of this specimen. The steel base of this tinplate was an early example of cold-reduction material, and was subject to the phenomenon known as fluting.

† See Fig. 11.

The experiments demonstrate that the compound layer revealed at potential pore sites may have a lower porosity than that associated with the layer revealed by chemical detinning, owing to its capacity for entangling an amount of free tin which depends on the amount of iron-tin compound present. The brittleness of this combined layer is shown to be high, and thus formulates an additional explanation of the mechanism by which the protection afforded to the steel base at potential pore sites breaks down easily upon slight deformation.

(3) *Macroscopic Variations over Individual Specimens.*

The third order of variation of the thickness of coating, *i.e.*, those effects such as grease lines,[3,4] scruff bands,[7] ripples,[16] &c., was qualitatively investigated by means of a new technique. The interference fringe method[16] was hardly convenient for this type of work, since it is desirable to survey a fairly large area of tinplate at one time.

Reflection Method.

When a diverging light beam is reflected from an irregular surface the concavities of this surface act as mirrors producing conjugate foci at points varying in distance from the surface with the radius of curvature of the concavities. A method based on this principle was found to be convenient for obtaining an idea of the presence and distribution of irregularities of surface which were too dispersed to be appreciated readily by the interference fringe technique. The method was as follows:

A beam of white light from a motor-car head lamp bulb was

focused on to a 1-mm. dia. pin hole and arranged to diverge from it on to the surface of the specimen to be examined. The distance of the light source from the specimen (Fig. 8) was fixed at 40 cm., which gave an illuminated circle on the specimen about 5 in. in

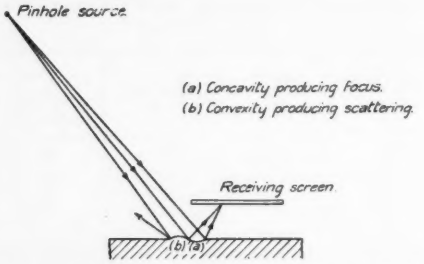


FIG. 8.—Diagrammatic Representation of Optical Technique.

dia. The reflected beam was received on a screen to which could be attached a sheet of gas-light photographic printing paper, the angle between the incident and reflected beams being just sufficient to obviate any cutting of the incident beam by the receiving screen. For the main series of photographs shown in Figs. 12–18 the distance of the screen from the specimen was maintained at 6 cm. In each of these figures the direction of tinning is vertical on the page, the front end being at the bottom.

It is obvious that since the arrangement is a simple reflecting system it could be employed to measure the focal length of concavities and therefore their approximate depth. It has not, however, been so employed by the author at present, being used qualitatively rather than quantitatively. The images are not all optically sharp for the same screen distance, and the distances of 40 and 6 cm. gave the most satisfactory general picture. It was convenient also that the linear magnification of macroscopic periodic effects was approximately unity. In considering the figures it should be remembered that these are actually negatives, the parts which are white being the images of those portions where the incident light is scattered and the black part where it is focused. From a study of Fig. 8 it will be appreciated that a convexity will cause scattering (white in the figures) while a concavity will collect the light. Figs. 12–18 are reflection photographs of a series of specimens from ordinary commercial tinplates with tin yields ranging from 1 lb. 5 oz. to 13 lb. per basis box. These figures show that lines of convexity (*i.e.*, ridges), together with associated concavities (troughs), appear in the direction of tinning and in the same positions and configurations as the grease-line structure. This phenomenon is commented upon later. The effect at right angles

to the direction of tinning (*see* Hothersall and Prytherch [7]) is clearly seen in Figs. 12, 13, 15, 16 and 17.

It appeared desirable that the results obtained by the reflection method should be confirmed by a procedure not depending on an optical method, and capable at the same time of quantitative interpretation. Various specimens, the irregularity of surface of which had been previously estimated by the reflection method, were therefore detinned slowly, and the structure was observed at progressive stages of the removal of tin (*cf.* Wernlund [17]). A number of reagents were used for slow detinning, the two most successful being found to be the following :

(1) 33% of Clarke's solution [10] in distilled water.
(2) Concentrated hydrochloric acid.

The use of dilute Clarke's solution suffered from one disadvantage in this application, in that it was necessary frequently to swab off the antimony film to observe the progress made. Hydrochloric acid does not suffer from this disadvantage but does attack the steel base slightly *via* the pore sites. It is necessary to mention that the cut edges of the specimens were always stopped off with " Necol " or Chatterton's compound, since, if this procedure was not resorted to, detinning occurred at a much greater rate towards the edges, and in the case of concentrated hydrochloric acid measurable attack of the steel base took place. The results recorded in Table VI. were obtained by what was considered to be the most convenient procedure, that is, detinning in concentrated hydrochloric acid until the required structure was thrown up, then estimating the average free tin yield by completing the detinning first in sodium plumbite solution and finally in Clarke's solution. The curve in Fig. 9 records a check experiment in which dilute Clarke's reagent only was used.

TABLE V.—*Detinning Experiment.*

Time. Sec.	Tin Removed.		Remarks.
	Gramme.	Oz. per basis box.	
0	0	0	
60	0·0250	4·1	No compound showing.
240	0·0785	13·0	No compound showing.
420	0·1430	24·0	No compound showing.
600	0·2150	36·0	Compound revealed at base of troughs.
780	0·2880	48·0	Tin broken up into patches.
End (23 min.)	0·4125	68·0	All tin removed.

The detinning experiments, typical cases of which are recorded in Tables V. and VI. and Fig. 9, confirm the results obtained by

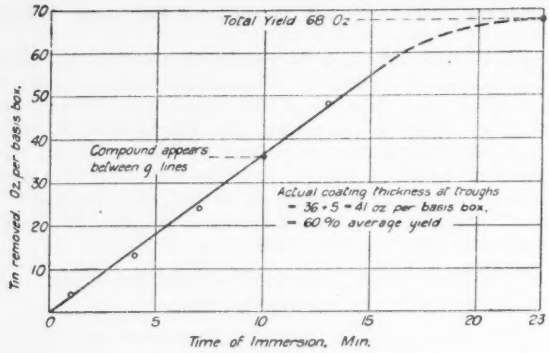


FIG. 9.—Estimation of Size of Irregularities by Progressive Detinning (*see* Table V.).

TABLE VI.—*Detinning Experiments. Ratio of Minimum to Average Coating Thickness at which Compound Appeared.*

Mark.	Min. Coating Thickness. *A.*		Average Tin Yield. *B.*		Ratio *A*/*B*. %	Remarks.
	Lb.	Oz.	Lb.	Oz.		
R		15	1	9	60	Compound revealed at grease-line troughs.
A		14	1	9	56	Compound revealed at ripple marks.
J	2	9	4	4	60	Compound revealed at grease-line troughs.
K	8	5	10	6	80	Compound revealed at grease-line troughs.

the reflection method. As the coating tin was progressively removed, the compound generally first appeared at positions between the grease lines, indicating that the *minimum tin coating thickness* occurred here. As detinning was carried further, it was noticed in some cases that the line of tin remaining at the site of the grease line began to split up periodically along its length, indicating that a further variation occurred at right angles to the direction of tinning. On a specimen which exhibited pronounced ripples at right angles to the direction of tinning, the minimum tin coating thickness was discovered at these marks, the grease-line troughs appearing at a later stage. The presence and magnitude of these various irregularities have further been confirmed by the interference method, and by a magnetic method (*see* Hoare and Chalmers [18]).

Photographs of partially detinned specimens are given in Figs. 19–21. Fig. 19 shows straight grease lines, the tin remaining along the site of the lines (corresponding to reflection photograph Fig. 15);

Fig. 20 illustrates the banded structure and grease-line troughs corresponding to reflection photograph Fig. 16, and Fig. 21 shows the branched grease-line structure corresponding to reflection photograph Fig. 14. The quantitative interpretation of these results given in Tables V. and VI. depends upon the assumption that the tin is removed evenly from the whole surface of the specimen, and although the extent to which this is not exactly so is insufficient to invalidate the quantitative result, the phenomenon is nevertheless worthy of notice. The rate of attack and dissolution of the coating tin by etching reagents varies slightly from crystallite to crystallite, apparently according to the angle between the lattice orientation and the general plane. This effect can be noticed in Fig. 19.

Types of Macroscopic Irregularities.

From a consideration of the various experiments described above it will be appreciated that there are three general types of macroscopic irregularities present.

(*a*) A periodic effect in the direction of tinning.
(*b*) A periodic effect at right angles to the direction of tinning.
(*c*) Irregularities due to the crystal structure of the coating (*see* Fig. 18).

These variations of coating thickness are further shown to be associated with :

(1) Transverse ripples.
(2) A secondary transverse effect.
(3) Potential and normal pores.
(4) Grease lines and grease marks.

Transverse Ripples.—It is considered that the term " transverse ripples " should be confined to those marked linear effects which are plainly caused by independent vibration of the sheet as it passes through the nip. That this effect consists of parallel ridges and valleys in the coating was established by Hoare and Chalmers[16] and confirmed by Hothersall and Prytherch.[7] It is possible to produce this effect at will, merely by imparting vibration to the sheet as it passes through the air-grease interface. The phenomenon is intrinsically independent of the grease-pot rolls, since it can be obtained on coatings tinned by simple immersion. It appears to be clearly due to disturbance of the grease-tin interface by the production of ripples.

Secondary Transverse Effect.—A transverse effect occurring on all grades of tinplate and essentially independent of obvious ripples was first noticed by Hothersall and Prytherch.[7] The fact that this banded structure was associated with the distribution of porosity gave the conception considerable importance. This effect

was found only on plates of coke grade and appeared to be associated with the deposition of scruff (iron-tin compound, $FeSn_2$). This secondary transverse effect, besides being associated with a deposition of compound, is also associated with a variation of thickness of coating. This fact is now confirmed by the methods of progressive detinning, magnetic estimation, and by the reflection technique. As far as knowledge goes at present, the suggestion that it may be caused by conditions set up by oscillations of the working parts of the tinning machine would appear to be satisfactory. The deposition of scruff does not appear to be intrinsically connected with the effect, and may be caused, when it occurs, by predeposition of compound on the rolls by a vibratory movement between the rolls and the grease-pot brushes.* This explanation may also account for the fact that scruff bands were only observed on plates of low grade, in the manufacture of which the use of grease-pot brushes would be expected.

Grease Lines.—Grease lines, and lines of grease saucers, first noticed by the present author,[3,4] and since commented upon by Hothersall and Prytherch,[7] consist essentially of linear arrangements of saucer-like depressions in the coating. These individual depressions may be connected by narrow drip channels, or, on the other hand, they may be entirely separate. The linear formation loses its property of straightness when the tin coating is thin and the structure becomes tree-like, each grease line having branches along its length. The effect can be particularly noticed in Fig. 12, slight branching is observed in Figs. 13 and 14, while the lines are substantially straight in Figs. 15–17. Grease lines have the following formation properties:

(*a*) The lines are associated with runnels of grease which are established on the top pair of rolls in the grease pot before the sheet comes through, and persist in similar positions on the sheet and on the rolls during the passage of the sheet.

(*b*) Marked grease-line structures do not occur on the front end of tinplates.

(*c*) The lines become more widely spaced as the tin yield increases, those, for example, on a 14-lb. plate being sometimes as much as an inch apart. This effect is shown in Fig. 10, where the grease-line spacing has been plotted against the tin yield for a number of specimens selected at random.

(*d*) Provided that the tin yield is reasonably constant, increased speed appears to cause the lines to become less widely spaced. In this particular it should be remembered that high-grade charcoal tinplates are usually tinned at a speed which is much less than that generally employed for coke tinning, where brushes and tightly-set rolls are used.

(*e*) The lines become more widely spaced as the temperature of tinning is decreased.

* Suggested in private conversation with Mr. J. C. Prytherch.

(*f*) With thin coatings the lines appear to have a greater tendency to form auxiliary branches. This effect may be due to the speed of tinning, since on the specimen of Fig. 12, where the branching is marked, the tinning speed, though not quantitatively known, was described as very high. (Many of the properties described above may be appreciated by studying Figs. 12–21.)

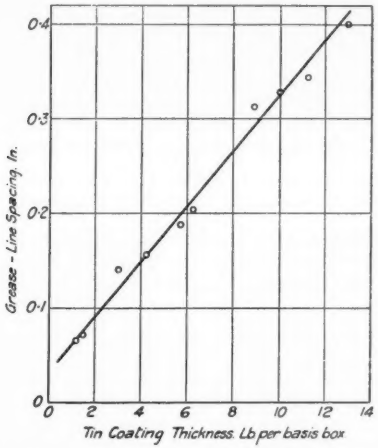


FIG. 10.—Relation of Grease-Line Spacing and Tin Coating Thickness.

The physical mechanism governing the formation of these structures has been discussed by Chalmers.[15]

Tin Ridges.—It is now shown that, associated with the saucers and channels of grease lines, there is a ridge in the coating, the corresponding concavity being of such depth that the minimum local coating thickness may only be 60% of the average tin yield over the whole specimen. The linear coincidence of tin ridges and grease lines would be expected, since the various interfacial tensions involved require that the grease shall be kept as far away from the compound layer as possible (*see* Chalmers[15]). The phenomenon of tin ridges is in course of investigation by the author in collaboration with Mr. D. J. Macnaughtan and Dr. Bruce Chalmers, and the results of this work will be published shortly. It may be stated here, however, that the formation of such ridges is an integral part of any physical process involving the distribution of a liquid layer on a solid surface by means of a roller, unless the conditions are such that the roller is not wetted by the liquid.[19] In the present case the tin ridges are formed at the tin-grease interface in the nip of tin lying beneath the grease at the top of the rollers in the grease

pot. The viscosity of the liquid tin, although low, is sufficient to prevent the elimination of the structure, either by spreading or spheroidisation, and the ridges persist as the tinplate passes through the grease-air interface. Here, by a precisely similar mechanism, grease ridges are formed, which, according to the mechanism explained above, are naturally superimposed on the existing sites of tin ridges. This line of grease spheroidises, and, by exerting its interfacial tension with the still molten tin, causes the formation of the familiar saucers and channels on the crest of the tin ridge.

The presence of tin ridges is undesirable from two points of view. First, as has been shown, the variation of coating thickness is capable of producing local and over-sheet increases of porosity. Secondly, in some cases the irregularities are strongly marked and may produce an undesirable appearance on lithographed or lacquered tinplates.[20]

Effect of Cleaning on Porosity.

In view of the fact that Hothersall and Prytherch [7] found that a large amount of porosity was attributable to the cleaning operation, a brief mention of some experiments in this connection would appear to be relevant to the present paper.

From a series of experiments which have covered numerous factors, chiefly tin yield, pressure and type of absorbent material, the author has been able to draw some fairly definite conclusions. In order to obviate the effect of arbitrary differences of porosity from specimen to specimen, the procedure employed was to subject each untreated specimen to the hot-water test, photograph, derust electrolytically, treat by any particular method, clean and retest for porosity.

The following conclusions were reached :

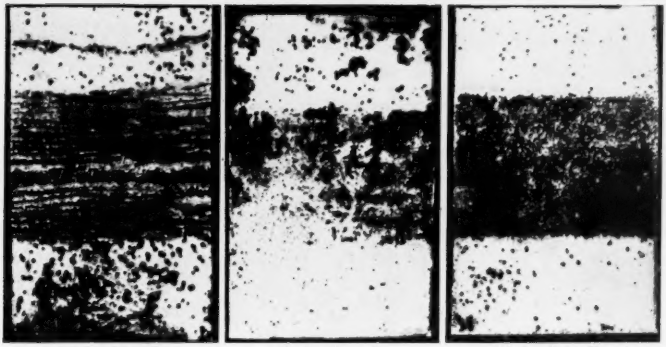
(1) The type of absorbent used had little effect on the increase of porosity. This conclusion has two exceptions. (*a*) The use of flue-dust is deprecated, since in concentrations of only 1% in bran, considerable scratching occurred. (*b*) One sample of sawdust examined contained a number of sharp particles which caused a fair amount of scratching. This effect was eliminated by sieving the sawdust.

(Note : Eleven materials and numerous mixtures were examined.)

(2) The increase of porosity with cleaning depends on the tin yield. When the tin yield is above 4 lb. per basis box the numerical increase of porosity is small. Above 8 lb. per basis box no increases were obtained.

(3) A marked effect of the cleaning operation is the enlargement of existing pore sites. This is particularly so in the case of thin coatings.

(4) The increase of porosity varies enormously with the pressure between the specimen and the polishing medium. It is hoped that this effect will be investigated more carefully in the future.



(*a*) Specimen *R*. (*b*) Specimen *J*. (*c*) Specimen *K*.

FIG. 11.—Effect of Slight Deformation on the layer "compound plus entangled tin."

REFLECTION FIGURES OF COMMERCIAL TINPLATES OBTAINED BY THE OPTICAL TECHNIQUE.

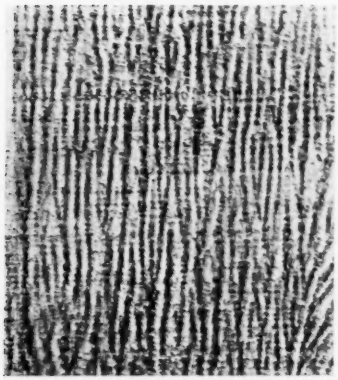


FIG. 12.—1 lb. 5 oz. of Tin per Basis Box.

FIG. 13.—1 lb. 9 oz. of Tin per Basis Box.

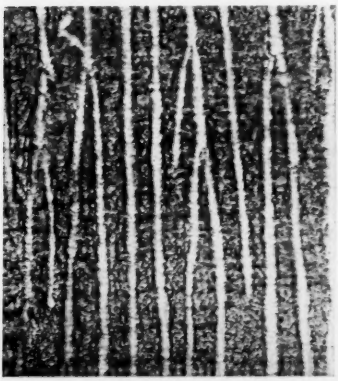


FIG. 14.—2 lb. 3 oz. of Tin per Basis Box.

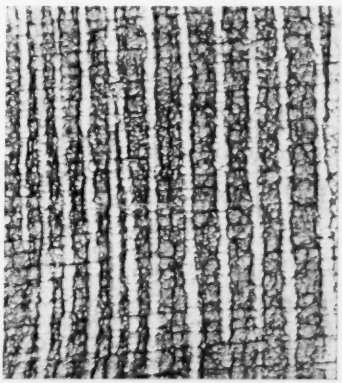


FIG. 15.—3 lb. 8 oz. of Tin per Basis Box.

(Micrographs reduced to four-fifths linear in reproduction.) [*Hoare.*

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Reflection Figures of Commercial Tinplates Obtained by the Optical Technique.

Plate VII.

Partially Detinned Tinplate.

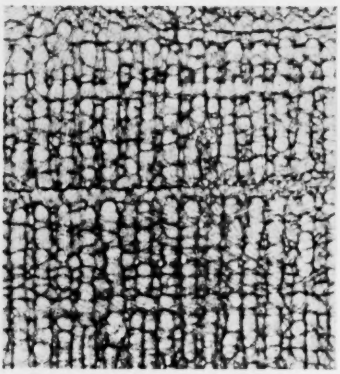

Fig. 16.—4 lb. 4 oz. of Tin per Basis Box.

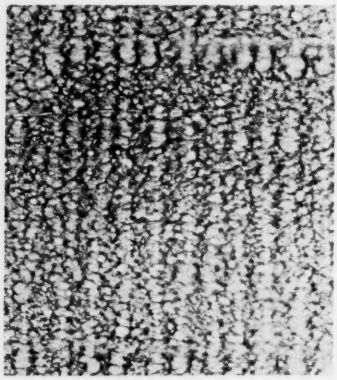

Fig. 17.—5 lb. 10 oz. of Tin per Basis Box.

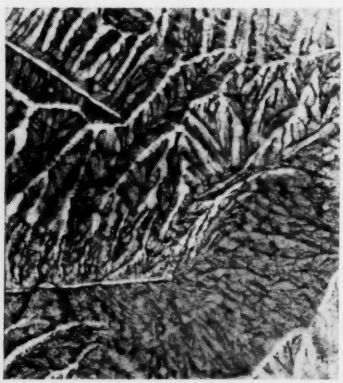

Fig. 18.—13 lb. of Tin per Basis Box.

Fig. 19.—Straight Tin Ridges.

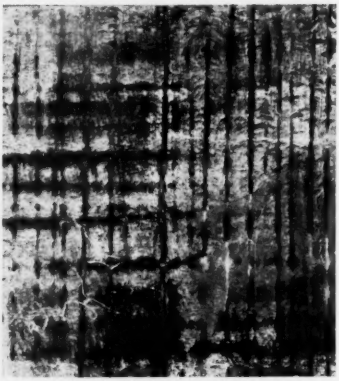

Fig. 20.—Longitudinal and Transverse Structures.

Fig. 21.—Branched Tin-Ridge Structure.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Hoare.*

[*To face p.* 119 P.

(5) From an examination of commercially cleaned tinplates it appears that cleaning porosity is due to isolated particles in the absorbent or on the rolls, rather than to any intrinsic general property of the absorbent itself. The general abrasion of the coating which can be perceived under the microscope does not appear to be sufficiently intense to produce much increase of porosity (except possibly when the tin yield falls below that normally employed). The scratches which do produce porosity are usually quite distinct from the general abrasion, and lead one to suspect that they may be due to foreign particles.

Generally it is possible to suggest that (*a*) attention should be paid to the cleanliness of operation, and the intrusion of grit and dirt obviated as far as possible; (*b*) the *minimum* pressure which achieves the desired result should be used; and (*c*) the use of hard and sharp abrasives (particularly such as flue-dust) should be avoided.

Acknowledgments.

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Acknowledgment is also made to the Governors and Principal (Mr. George Patchin, A.R.S.M., M.I.M.M.) of the Sir John Cass Technical Institute for the provision of facilities.

The author wishes to express his thanks to Dr. Bruce Chalmers for his very valuable practical advice and assistance, and to Mr. H. J. Taffs, F.R.P.S., and Mr. R. M. Angles, who assisted with the photography and the experimental work.

It is felt that expression should again be made of the debt of gratitude which the author owes to many friends in South Wales and Monmouthshire, without whose practical knowledge and willing assistance little could be done in an investigation of this type.

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(21) H. S. RAWDON: "Protective Metallic Coatings." 1928: The Chemical Catalog Co.

CORRESPONDENCE.

Dr.-Ing. F. PETER (Dillingen, Germany) wrote that the author enumerated four factors which might be considered as the cause of porosity on tinplate. It appeared to be very necessary to point out that, if the porosity test were carried out immediately after the sheets had left the grease pot, and after previous degreasing, the presence of non-reactive areas on the steel basis sheet had a very great effect on the porosity in the formation of both potential pores and also normal pores. Defective pickling and less active flux must also be included in this group of causes. Referring to the remark that the fourth major effect was to be sought in the methods of cleaning, he would point out in addition that the mode of assorting and of packing, and, in particular, manipulation in the canning industry increased the extent of the porosity very much, and that in this industry far too little care was taken in manipulation. In this connection it might be mentioned that so far no works had made the experiment of lacquering cans in the finished state; the lacquer was applied to the unworked sheet, so that the damage which occurred during manipulation was found in the lacquer as well as in the tin layer.

No objection could be raised against the hot-water test used. In the hands of an expert it could be particularly serviceable. Nevertheless, on account of its simplicity as a comparative test, the modified ferricyanide test could well be used in practice, because in laying on a filter paper of any desired size, soaked in ferricyanide solution, no care need be taken of the cut edges and the sheet could be used again. After testing one side the other side could also be examined. In any case the test showed whether the porosity of sheets produced in a given machine was acceptable or excessive.

Regarding the author's comments on the unequal coatings of tin on the two sides of a tinplate, he would say that, in testing, the non-uniform unilateral tin yields should be allowed for by estimating the tin yield only on the side already used for determining the porosity. This should also, perhaps, be considered in relation to the fact that the under side was always somewhat more porous because the thickness of the tin coating on it was consistently lower. This was not to be attributed solely to the difficulty of escape of flux reaction products, but was also due to the fact that, owing to the bending of the sheet, the lowest pair of rolls removed the tin more completely from the under side than from the upper side. Some time ago, he had started to make such determinations of the tin coating thickness on one side, and simultaneous porosity tests. The results were not available yet in sufficient number for conclusions to be drawn. It might be mentioned here that with most tinplate, even in the already packed boxes, the upper and under sides of the sheet could be recognised by the list end.

The theoretical explanation of the building-up of the thickness of the tin coating was logical and interesting. It must be remembered, however, that, depending on the rate at which the sheets were put through, the opposing effects of gravity and viscosity could produce an increased tin yield sometimes at the front end, and at other times, at lower speeds, at the list end. When it was put through at suitable speeds a fairly uniform tin yield could be obtained on charcoal tinplate in machines without brushes.

That the lower tin yields obtained by treatment in palm oil at a temperature above 250° C. possessed a lower porosity than those produced by chemical detinning was, in his opinion, to be attributed to the closing of potential and actual pores by the cleaning action of the palm oil on the surface of the sheet, *i.e.*, subsequent tinning of the pores occurred in the palm oil.[1] On the contrary, chemical detinning laid bare particularly the actual pores, because here the detinning never took place so gently and uniformly as in the palm oil.

The reflection method, in conjunction with the detinning test and magnetic testing, established clearly the fact that the tin was very unevenly distributed on the surface of the sheet. The present experiments showed plainly that, even when the most careful precautions were taken in hot tinning to produce the most uniform tin yield over the whole surface, local differences of up to 50% in the tin yield would still remain. In this connection it was desirable that all sheet works working to-day with the hot-tinning process should pay great attention to the recently developed electrolytic method of tinning, because by this process uniform tin coatings of any desired thickness could be most easily obtained which were not dependent upon so many factors such as occurred in hot-tinning.

With regard to the various types of macroscopic irregularities, the appearance of the surface of commercial coke tinplate which had been passed at a rate of 9 m. per sec. through the tinning machine the top pair of grease pot rolls of which were covered with 50–80 mm. of palm oil, differed from that of the sheets used in the present research; the tin coating was covered with a pattern resembling fir tree needles. On these sheets (sample 2 from the Ætna machine), therefore, the transverse ripples, the coarse lines, the tin ridges and the troughs would have quite a different formation, the shape of which would be easily revealed by the reflection method. (In sample 2, the two sides revealed differences in the visibility of the pattern on the surfaces.) He (the writer) was not aware that such sheets were less suitable for printing or lacquering than sheets which had been run through at a velocity of 3 m. per sec. in manufacture; with these sheets also it would be interesting to determine whether a local reduction of the tin layer up to 60% took place.

[1] F. Peter and G. Le Gal, *Archiv für das Eisenhüttenwesen*, 1935, vol. 9, p. 286.

Concerning the porosity produced by cleaning, he would point out that every type of absorbent should be sifted before use; his own experiments agreed well with those of the author. The author's fourth point concerning the effect of cleaning on porosity was to be stressed, because with insufficient pressure the sheets remained dirty, whereas with too much pressure the porosity increased to an undesirable extent. If tiny particles of sheet and snippings remained after the tinplate had passed through the absorbent, trouble might arise, because, owing to their great hardness, these tiny tinned particles of steel could scratch the tin layer down to the basis material. These steel particles could be removed by means of magnetic drums or suitably arranged magnets, which must be continuously in operation.

Mr. R. TAGGART (London) wrote that a detailed examination of the relationship between tin yield and porosity now in progress dealt with the restricted field of coke plate (1–2 lb. of tin per basis box). In general, the results were in accordance with Mr. Hoare's findings, but certain points on which the writer's experience differed might possibly be of interest to those who were mainly concerned with coke plate.

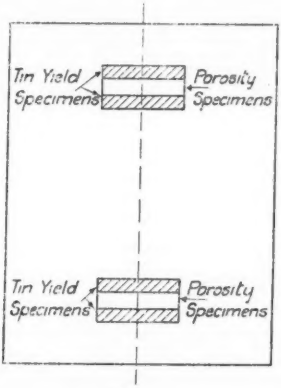

FIG. A.

On the question of sampling, the work so far done suggested that a sampling scheme with the specimens cut at right angles to the direction proposed by Hoare was to be preferred (Fig. A). Porosity determinations made on both sides of individual sheets showed that the lower face of the sheet was often of lower porosity than the upper, this feature being a constant characteristic of sheet from one particular mill. It would thus appear that a more detailed examination of the source of these differences was desirable.

The variation of tin yield along the sheet was treated by Mr. Hoare as being a feature of the more heavily coated grades. The writer's experience was that this variation occurred in coke-quality plate also—sheets from some mills having a much more strongly marked gradation than any shown by the author, while other brands were very nearly uniform from leading to list edge.

Examination of the transverse variation showed irregularities

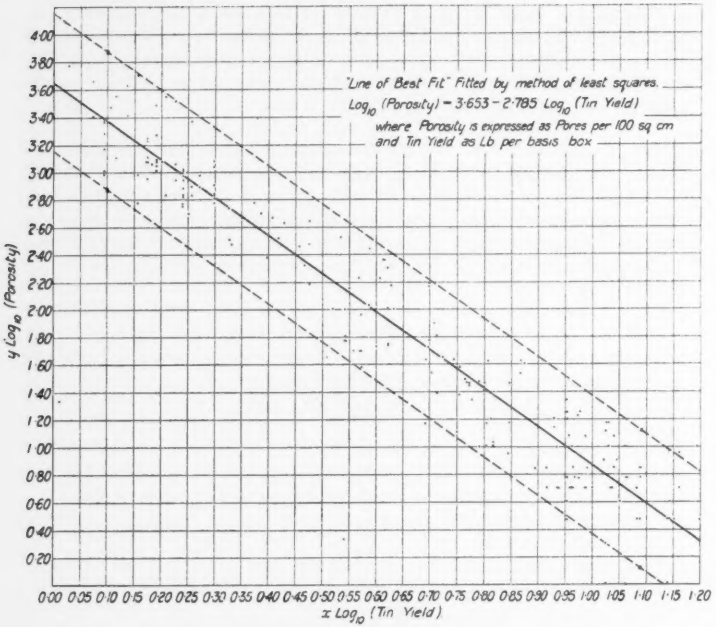
"Line of Best Fit" Fitted by method of least squares.
Log10 (Porosity) = 3·653 − 2·785 Log10 (Tin Yield)
where Porosity is expressed as Pores per 100 sq cm
and Tin Yield as Lb per basis box
y Log10 (Porosity)
x Log10 (Tin Yield)

FIG. B.—Drawn from Data given in the Author's present Paper.

which were sometimes considerably more complex than a simple gradation from one side to the other.

The writer had to thank Mr. Hoare for giving him the opportunity of making a detailed study of the relationship between tin yield and porosity. With his co-operation it had been found that the author's curved graphs (Figs. 2 and 3) could be reduced to a linear form by plotting the logarithm of the porosity against the logarithm of the tin yield (Fig. B). This relationship could be expressed by the equation:

$$\text{Log}_{10}\,(\text{porosity})_W \pm 0{\cdot}505 = 3{\cdot}653 - 2{\cdot}785\,\log_{10}\,(\text{tin yield}),$$

the second term giving the limits within which 95% of the results lay.

A similar equation expressing the mean course of the data given by Peter and Le Gal [1] (Fig. C) was :

$$\text{Log}_{10}\,(\text{porosity})_F = 2{\cdot}19 - 2{\cdot}553\,\log_{10}\,(\text{tin yield})$$

In these equations :

$(\text{Porosity})_W$ = number of pores per 100 sq. cm. (hot-water test)
$(\text{Porosity})_F$ = " " " " " (ferricyanide test)

Combining these equations gave :

$$\text{Log}\left(\frac{(\text{porosity})_W}{(\text{porosity})_F}\right) = 1{\cdot}463 - 0{\cdot}232\,\log_{10}\,(\text{tin yield}),$$

a further equation giving the ratio of the number of pores indicated by the hot-water test to the number indicated by the ferricyanide

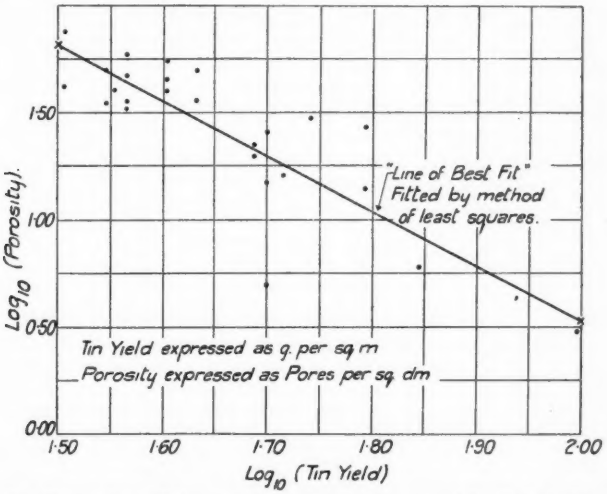

FIG. C.—Drawn from Data given in a paper by Peter and Le Gal, *Archiv für das Eisenhüttenwesen*, 1935, vol. 9, p. 285.

test for any given tin yield. This was possibly of value to those studying results obtained by the two methods.

Perhaps the most valuable section of Mr. Hoare's important paper was his description of the types of macroscopic irregularities and his recognition of their periodic character. The writer's work included an attempt to trace these to their sources in the vibration of the working parts of the machine, or of the sheet itself.

[1] *Archiv für das Eisenhüttenwesen*, 1935, vol. 9, p. 285.

It might well be that the frequency of occurrence of scruff bands was to some extent determined by the substance of the plate.

Mr. A. W. HOTHERSALL (Research Department, Woolwich), referring to the author's discussion of the variations in tin yield over individual sheets on a large scale, wrote that it might be useful to record the analysis of some results, given in Tables A and B, obtained at Woolwich by Mr. J. C. Prytherch, which confirmed the author's statements on p. 106 P. It was interesting to note that this analysis showed that both the thickness and porosity were subject to considerable variation over a single sheet. Tin yields had a definite tendency to vary progressively from end to end (*i.e.*, parallel to the direction of tinning) and from side to side, but the porosity appeared to be distributed in a more haphazard manner.

TABLE A.—*Tin Yields.* (*List edge removed and sheets cut into squares approx.* 4 × 4 *in. in size.*)

Sheet Mark.	No. of Specimens Tested.	Average Tin Yield per Basis Box.	Deviations from Average.		
			Maximum. %.		Mean. %.
			Plus.	Minus.	
A	35	2 lb. 1·7 oz.	49	32	20
B	35	2 lb. 2 oz.	75	32	27
C	26	1 lb. 5·8 oz.	16	22	9
D	13	1 lb. 7 oz.	14	11	7
E	35	2 lb. 7 oz.	30	28	11

TABLE B.—*Hot-Water Porosity Tests.* (*Sheets,* 20 × 14 *in., cut into* 15 *squares approx.* 4 × 4 *in. List edge removed.*)

Sheet Mark.		Average Pores per sq. dm.	Deviations from Average.		
			Maximum. %.		Mean. %.
			Plus.	Minus.	
F	Face	686	24	22	15
	Reverse	884	76	30	16
G	Face	961	39	25	25
	Reverse	1455	36	33	18
H	Face	990	120	54	40
	Reverse	930	47	33	18
I	Face	317	90	29	28
	Reverse	532	107	50	31
K	Face	367	94	35	34
	Reverse	375	70	52	33
L	Face	265	100	60	37
	Reverse	460	75	72	27

This observation suggested the possibility that some factor other than variations in the tin yield was responsible for porosity, but it should be noted that the tin yields were averages for both sides of the specimen, whilst the porosity figures were given for each side separately.

With reference to the author's experiments on stripping in palm oil and, in particular, to the conclusions drawn on p. 111 P, he thought that no relation between the porosity of the compound layer after chemical detinning and after stripping in palm oil would be expected, since the latter process involved an increase in the thickness and consequently a decrease in the porosity of the compound layer itself, quite apart from any effect of entangled tin. Whilst entangled tin might reduce the porosity of the alloy layer, it was interesting to note that the porosity of specimens *H* and *R* in Table IV. (15 and 11 oz. of alloyed tin per basis box) was comparable to that of a chemically detinned plate carrying 13 oz. of alloyed tin per basis box (40 pores per sq. cm.), as reported in a previous paper.[1] The increase in thickness of the compound layer on stripping in palm oil might also be expected to reduce its resistance to rupture on deformation.

The author's optical method of examining the surface of tinplate was an interesting and valuable development in technique. It was noted that the existence of transverse "scruff bands," which appeared in a previous investigation [2] to have an important relation to the problem of porosity in the tin coating, had been confirmed.

AUTHOR'S REPLY.

Mr. W. E. HOARE wrote in reply that he was very interested to receive these constructive contributions, and was encouraged by the fact that other investigators could confirm, out of their own experiences, many of the conclusions reached in the paper.

In outlining the causes of porosity he had aimed at a general grouping; thus defective pickling and less active flux would be included in group (i), p. 99 P. He agreed that one could not too often emphasise the necessity for care in the handling and manipulation of finished tinplate. It should be pointed out, however, that good progress was being made in this direction. Mechanical feeders for tin pots, automatic pile feeders on lacquering and slitting machines, and the increased use of more expedient transport facilities in works, reduced haphazard handling and consequent injury to the sheets. The device of shipping in large packages, typified by the "one-ton stillage," was also advantageous. Dr. Peter had mentioned the lacquering of finished cans. Judged by usual standards,

[1] A. W. Hothersall and W. N. Bradshaw, *Journal of the Iron and Steel Institute*, 1936, No. I., p. 232 P.

[2] A. W. Hothersall and J. C. Prytherch, *ibid.*, p. 205 P.

this procedure in the present stage of its development was rather costly; and this factor, coupled with certain technical difficulties which had not yet been entirely overcome, had so far discouraged its wide application. There was little reason to doubt, however, that the procedure would in time become more generally available for certain containers.

It was mentioned in the text of the paper that effects on opposite faces of the sheet had not been fully investigated. Since the time of writing, however, certain results had shown that the porosity of the under face was not always higher, and the coating thickness was definitely not *consistently* lower. It should be emphasised that this was a preliminary conclusion; Dr. Peter had rightly pointed out that a large number of results was necessary in order to reach a definite conclusion. Mr. Taggart had also raised this point, and his (Mr. Taggart's) finding, that lower porosity of the under face was a constant characteristic of the output of a particular mill, was highly indicative, and would repay further study. The author was, of course, familiar with the methods of spotting the faces of finished tinplates. He had found, however, that these were not quite infallible when an "international" range of deliveries was under examination, and had therefore thought it inadvisable to make use of them. If the output from only one tin pot were being examined, then the usual method of inspection of the list edge was quite satisfactory.

He was glad to have endorsement of the theoretical explanation, and the remarks touching on the speed of tinning were particularly interesting. The author intended to proceed to an investigation of the effects of varying tinning speeds, since preliminary experiments had given rather interesting results.

It was agreed that the action of stripping in palm oil would tend to flux some of the non-reactive areas and result in a lower porosity. The point he had intended to make here, however, was not so much concerned with the absolute porosity of the stable layer, but with the fact that this was extremely brittle, and consequently broke down very easily upon deformation (*vide infra*).

Referring to Dr. Peter's remarks on electrodeposited tin coatings, the author thought that attention should be drawn to the fact that it was hardly valid to compare the two methods when one was much more fully commercialised than the other. Caution should be used in claiming better uniformity of coating by electrodeposition from results obtained on experimental samples, since many of the irregularities found in the coating of hot-dipped tinplate could be ascribed to conditions implicit in large-scale manufacture. These would not occur in laboratory specimens treated under very ideal conditions.

Examination of Dr. Peter's "sample 2" by the reflection method revealed a normal type of irregularity on both sides (very similar to Fig. 13). One face of the specimen was, however, slightly "dry,"

and the structure was therefore not so easily discerned with the naked eye. The author would subject the specimen to a detinning test as soon as opportunity arose, and would communicate the result to Dr. Peter.

The author thanked Dr. Peter for his emphasis of the conclusions relating to the effect of cleaning on porosity and for his suggestion concerning the magnetic separation of foreign bodies.

Mr. Taggart's statement regarding a detailed examination of the relationship between the coating thickness and porosity of coke tinplates now in progress was most interesting. The results of such an investigation would be of major importance, since it was with coke-grade tinplates that the industry was chiefly concerned.

It would appear that Mr. Taggart's method of sampling was dictated by his findings, mentioned later in his contribution, relating to complex variations in coating thickness from side to side of sheets. In assessing the merits of methods of sampling it was essential to consider both the purpose of sampling and the volume of sample that could be dealt with by the laboratory. If such complex transverse variations were assumed to be present and the purpose were to examine the relation between the two variables, then Mr. Taggart's method would be superior. If the purpose were to evaluate the properties of the sheet, the two methods would be of approximately the same value, since, in the author's method, transverse variations were taken into account by the staggered method of cutting the tin-yield samples (*see* Fig. 1). In the latter case preference might be expressed for the method involving the testing of only four samples instead of six. The latter point would be important in a works laboratory, where it was common experience for the chemist to have great difficulty in passing deliveries at a sufficiently fast rate to satisfy the production manager.

Referring to the matter of variation along the length of the sheet, it seemed that Mr. Taggart's conclusions were really very similar to his own (*see* p. 106 P). Since the paper had been written, some further results had been obtained and were recorded below :

Class.	No. of Sheets with Yield— Greater at List End.	Greater at Front End.	Equal.
Coke grades	10	1	1
Charcoal grades	14	1	0
Total	24	2	1

The mathematical analysis of the tin yield and porosity figures recorded in Figs. 2 and 3 was extremely valuable, and the author would like especially to thank Mr. Taggart for having included this in his contribution. The analysis would simplify the practical application of the results, and further mathematical manipulation would be greatly facilitated.

The possibility of converting ferricyanide test results to hot-

water test results was a point which the author thought was very well taken. It was necessary to notice, however, that ferricyanide testing techniques varied among themselves, and it would therefore be necessary to arrive at a separate conversion equation for each technique. Mr. Taggart's suggestion that the frequency of scruff bands might be to some extent determined by the substance of the plate seemed theoretically sound. A plate of lighter substance would have a lower natural frequency, and transverse periodic effects would, other things being equal, tend to be more widely spaced.

The results recorded in Tables A and B in Mr. Hothersall's contribution illustrated very well the large variations in the tin-coating thickness and porosity existing on single sheets. When a sheet was tinned in the ordinary way a certain group of factors would cause variations in the number of non-reactive areas and the frequency distribution of their size. A second group of factors (which might conceivably also be correlated with some of the first group) would subsequently cause variation in the tin-coating thickness, and consequently result in exposure or non-exposure of the various non-reactive area size-groupings. It was therefore necessary to take into account a large number of experiments in order that their partial effects could be established.

The author agreed with Mr. Hothersall's statement that no relation would be expected between the porosity of the iron-tin compound layer exposed by chemical detinning and that of the stable layer remaining after stripping in palm oil. An increase of thickness of the layer, and the fluxing action mentioned by Dr. Peter, would tend to decrease its porosity. It was found, however, that on selectively detinning the stable layer in plumbite, a significant increase of porosity was obtained. Thus the entangled tin did appear to be exerting some effect. On p. 109 P he had intended to infer a qualitative rather than a quantitative similarity between the stable layer and the base of a potential pore. Mr. Hothersall's point relating to the porosity of specimens *H* and *R* (Table IV.) was an interesting one. The author thought that the similarity might be explained by the fact that the compound layer on Hothersall and Bradshaw's 13-oz. specimen had probably been formed by prolonged soaking in tin at a relatively low temperature, and the specimen had subsequently passed through tinning rolls. Although of like amount, this compound layer might tend to have a lower porosity than that existing in the stable layers such as *H* and *R*, which were formed relatively rapidly and had not passed between rollers. If this explanation were correct, it could be reasoned that it was the entangled tin present which had reduced the porosity of the stable layer to a comparable value.

The author thanked Mr. Hothersall for his reference to the optical technique. The existence of transverse structures, first discovered by Hothersall and Prytherch, had been abundantly confirmed by this method of examination (*see* Figs. 12, 13, 15 and 16).

NOTES ON SOME RECENT EXPERIMENTS IN CONNECTION WITH THE SPRAYING OF STEEL BY THE WIRE-FED METAL-SPRAYING PISTOL.*

By RICHARD R. SILLIFANT (London).

(Figs. 1 to 10 = Plates VIII. to X.)

Synopsis.

Metal-spraying technique, as applied to the re-surfacing and building-up of machine parts, is described. Some experiments in connection with the fuel gases—compressed coal gas, hydrogen and dissolved acetylene—with respect to the deoxidising effects of reducing flames are explained. The use of nitrogen as an impelling medium in place of compressed air, to minimise oxidation, is also described. Further, the results of the heat treatment of sprayed steel, using dissolved acetylene as a fuel gas and compressed nitrogen as the impelling medium, are explained.

Introduction.

The metal-spraying process is rapidly finding new and improved uses in a wide field in industry, and, apart from its uses as a means of combating the corrosion of iron and steel in the atmosphere and at elevated temperatures, other more specialised applications are coming almost daily into general practice.

Papers have been presented before learned societies all over the world dealing with the metallurgical and other aspects of metallic deposits made by this method,[1-4] but the field is so large, covering as it does the application of numerous metals and alloys to various bases, that research upon the process, to be useful, should be confined to the examination of deposits of one particular material at a time.

The spraying of the various carbon steels and also, more recently, alloy steels for the purpose of re-surfacing and building-up worn machine parts has now been adopted as standard practice in many engineering works in Britain and abroad, and it is the object of this paper to explain some experiments conducted with a view to improving the quality of deposits made in this kind of work, using the wire-fed type of pistol.

This type of pistol is in use in various forms in most industrial countries. Certain essential features are, however, common to all forms of pistol.

* Received May 24, 1937.

The pistol may be regarded as a combination of two elements, each having a distinct function, which work in perfect synchronism. One element comprises mechanism for feeding the wire at a predetermined speed into the second element, which consists of the means for melting, "atomising" and impelling the resultant particles of metal. The mechanical element, known as the wire-feed mechanism, comprises an air-actuated turbine, which drives a pair of wire feed rollers through a series of reduction gears. The second element, known as the gas head, is composed of a taper valve for regulating, first, the air for driving the turbine, and, secondly, the oxygen and fuel gas used for melting the wire, together with a series of ports, gas and air channels for mixing the oxygen and fuel gas in the desired manner and for conducting air to atomise and impel the molten metal. All these parts, *i.e.*, the air turbine, gears, taper valve and gas head, are mounted in and upon an aluminium case some 4 in. long, 3 in. wide and 3 in. deep, attached to a suitable handle or grip.

In some forms the pistol is not restricted to the use of wire alone, but rods up to $\frac{3}{16}$-in. in dia. may be used in cases where heavy deposits are required. Wire-fed pistols are designed normally to use either compressed coal gas, hydrogen or acetylene as the fuel gas burned when mixed with oxygen, and the kind of fuel gas used in given circumstances depends upon the cost, locality of the job and convenience. In many cases, the cost of operation is the controlling factor, and therefore compressed coal gas is used in most commercial spraying plants.[5]

Building-up by Metal-Spraying.

Before describing the experiments which form the subject of this paper, some general remarks on the method of applying steel coatings to shafts and similar parts may be of interest.

The article to be treated is set up in a lathe or similar tool, and the area to be coated is reduced slightly undersize, usually $\frac{1}{32}$ in. per in. dia. The surface is roughened or prepared by a V-pointed tool, mounted below centre, making between 20 and 30 cuts to the inch.

The metal-spraying pistol is then mounted on the tool post of the lathe, set in operation and fed automatically across the work, the spray being directed upon the work-piece above the centre line and the work-piece rotated at a maximum peripheral speed of approximately 20 ft. per min. during the operation, whilst the pistol traverses approximately 0·010 in. per revolution of the work-piece.

The spraying is continued until sufficient metal has been deposited to allow of finishing to the original diameter of the work-piece.

Microstructure of the Deposit.

This method produces a structure of the type illustrated in Fig. 1, which shows low-carbon steel (0·09% of carbon) sprayed with coal gas as the fuel gas. The junction between the deposit and the base is shown in Fig. 2. It will be seen that the structure of the deposit is "piled up," *i.e.*, the particles are irregular in size and are piled together like stones in a heap.[6] The particles take their peculiar form because they are forcibly thrown together in a plastic or nearly molten condition, and therefore cling together and to the base by virtue of the shape that they assume on impact.

The size of the sprayed particles is not related to the grain size of the same metal in the cast form. One sprayed particle may contain a part, or one or more whole and part grains. Each sprayed particle is enveloped by a skin of oxide which is thinner on the striking face of the particle than on the outer face. This is shown in Fig. 3, where the direction of flight of the particles is indicated. These oxide layers are, to a large extent, responsible for preventing the resolution of the sprayed mass into a normal structure. Each sprayed particle must be regarded as a small fragment of metal, the structure of which has no definite orientation or relative position with respect to that of adjacent particles. From a purely metallurgical point of view, the layers of oxide are looked upon with suspicion, since they cause the sprayed deposit to be of poor quality. Further, the oxide content of a sprayed mass of steel artificially hardens it to the point of brittleness and tends to produce low tensile strength.

Whilst for many normal applications this inclusion of oxide does not in any way affect the usefulness of deposits, there are certain fields in which deposits of steel and its alloys can be made by spraying if the oxidation can be minimised or avoided altogether, since it is clear that if a more normal structure can be obtained in a deposit, improved mechanical properties will be imparted to it, thus widening the scope of usefulness of the process.

With these considerations in mind, the spraying method was examined in its entirety, from the nozzle functions of the pistol to the actual deposition of the "atomised" metal, in order to ascertain where oxidation occurs and what benefits could be expected if it were eliminated.

This examination revealed that oxidation could occur in four distinct phases :

(1) In the flame zone, if this contains excess oxygen,

(2) when the molten metal is removed from the tip of the wire by the air blast,

(3) on the surface of the sprayed article by exposure of the metal particles to the air blast and to the atmosphere, and

(4) if the sprayed article becomes excessively heated.

Rollason [7] has pointed out that oxidation can be lessened if a reducing flame is used and the pistol held close to the work, but states that neither of these suggestions is practicable. The solution of the problem of oxidation lies elsewhere, and assuming that the possible causes under (1) and (4) are avoided by using a strictly neutral flame and keeping the work cool, the main cause of oxidation is the air blast at the nozzle. Some means for deoxidising this was therefore necessary, and in this connection observations were made upon the behaviour of neutral and reducing flames, with three different fuel gases, namely, compressed coal gas, hydrogen and dissolved acetylene.

It was found that compressed coal gas and hydrogen did not produce stable flames when insufficient oxygen for complete combustion was supplied, so that the effects of excess fuel gas over oxygen could not be studied.

With dissolved acetylene, however, the position was different. As is known, acetylene requires roughly $2\frac{1}{2}$ times its own volume of oxygen for complete combustion. It will burn with a stable flame, however, with an approximately equal volume of oxygen, which happens to correspond with the conditions at the spraying nozzle. Under normal conditions, steel wire of 1 mm. dia. is sprayed with an oxygen pressure of 16–17 lb. per sq. in. and an acetylene pressure of 15–16 lb. per sq. in., the volumetric ratio of the gases being approximately 1 volume of acetylene to $1\frac{1}{4}$ volumes of oxygen. When a $1 : 1\frac{1}{4}$ mixture is used, the extra oxygen for complete combustion is taken from the atmosphere, which accounts for the secondary flame. A lighted blowpipe shows this clearly. The intense bluish-green flame at the tip of the blowpipe is the $1 : 1\frac{1}{4}$ zone or primary flame. The long bluish tail is the secondary flame, which uses oxygen out of the atmosphere. In view of this, it was decided to assess the volume of oxygen in the blast air and to ascertain exactly how much of this was absorbed by the secondary acetylene flame in the type of pistol used for these experiments.

It was found that 0·4 cu. ft. of acetylene was used per min., and this consumed about 0·45 cu. ft. of oxygen in the primary zone. Approximately 12 cu. ft. of air per min. issued from the blast nozzle, and this contained roughly 2·3 cu. ft. of oxygen. As the secondary acetylene flame required a further 0·45 cu. ft. of oxygen, the majority of this was taken from the blast air. Thus, it was assumed that the total volume of oxygen left in the blast air amounted to roughly 1·8 cu. ft. per min. This, of course, applied to neutral flame conditions. When increasing amounts of acetylene were fed to the flame until instability was reached, the amount of oxygen left in the blast air was found to be a little less than 1·5 cu. ft. per min. at the point of instability.

The Use of an Inert Impelling Medium.

Even this comparatively small volume of oxygen at the tip of the wire was considered objectionable, so the use of an inert gas in place of the air blast as well as means for deoxidising the air were considered. As compressed nitrogen was available in cylinders, deposits were made using this gas, and the result is illustrated in Fig. 4, which shows a much improved deposit. The " piled-up " effect is still apparent, however, and it was decided to ascertain the effects of heat treatment upon a deposit made with nitrogen as the impelling medium, since it was believed that as so little oxide was present in these circumstances, recrystallisation of the sprayed deposit should take place without difficulty.

To this end, a bar of 0·30% carbon steel, $\frac{3}{4}$ in. in dia. by 4 in. long, was prepared and sprayed in the manner already described, and $\frac{1}{8}$ in. of steel, containing 0·09% of carbon, was deposited upon it, the only deviation from standard practice being that the surface was prepared by screw threading at 0·007 in. pitch instead of 0·040 in. pitch in order to obtain as intimate a contact between the deposit and the steel bar as possible. This coating was machined all over, and the bar was divided into two equal parts. One end of one part was polished, etched and examined under a microscope, and the junction of the coating and the core is shown in Fig. 5. It will be seen that the layers of oxide are almost entirely eliminated, and that the junction of the two metals is very intimate.

The second half of the sample bar was annealed at 900° C. for 1 hr., after which it was examined. It then had the appearance shown in Fig. 6. It will be noted that the oxide inclusion in the sprayed deposit was so small that it did not prevent diffusion of carbon from the core into the coating, as is shown by the decarburised layer near the original edge of the core. Because of this diffusion, all trace of the junction between the two metals has disappeared. Further, it will be noted that the coating has commenced to resolve into a definite crystalline structure, as indicated by the ferrite grains dispersed throughout the field.

Fig. 7 shows the same sample after 2 hr. heat treatment at 900° C., and here the resolution of the coating is even more marked, the individual particles of the original deposit having split up into grains.

Fig. 8 shows the sample as sprayed at a magnification of 1300 diameters, and this clearly indicates the deformation of one sprayed particle.

Comparison of this with Fig. 9 is very interesting. Fig. 9 shows the sample heated for 2 hr. at 900° C., at a magnification of 1300 diameters. There is so little difference between the structure of the sprayed deposit and that of the original bar, that difficulty was experienced in mounting the photograph. In order to show that the improved deposit indicated in the micrograph possessed

mechanical properties not present in normal sprayed deposits, a simple test was made as follows. A bar of the same diameter, only 9 in. long, was prepared, sprayed and treated in the same way. It was then bent cold through an angle of 90° and is illustrated in Fig. 10. It will be seen that the coating and the bar have become so homogeneous that the bending was accomplished without in any way dislodging or fracturing the deposit.

It was found that for the particular sample examined, 2 hr. heat treatment at 900° C. gave the optimum effect, and that no further change in the structure was apparent after treatment for a longer period than this.

The recrystallisation of the deposit and the temperature which will effect it depends on the calescence and recalescence points of the particular steel used, and these depend in turn upon the amount of carbon present. Thus a steel having a high carbon content will have a lower calescence point and will recrystallise at a lower temperature, and in a shorter time. It is believed that the possibility of using the principles outlined in this paper will allow of a form of case-hardening being effected without carburisation, since a high-carbon steel could be applied to a machine element by spraying, be refined by heat treatment, and then be reheated and quenched to obtain a hard surface. Thus the deposit would have the advantages conferred upon it by spraying, namely, abrasion resistance and oil-retaining properties due to slight porosity, coupled with perfect homogeneous bonding to the original base and a refined structure.

The question of adding known deoxidising agents, such as silicon, aluminium, magnesium, &c., to the wire itself is being considered, and an alternative to the use of compressed inert gases by way of deoxidising the air on commercial lines by static chemical means capable of regeneration forms the subject of present experiments.

As far as the carbon diffusion from the base metal to the coating is concerned, it is assumed that the higher the carbon content in the base material, the greater will be the absorption of it into the coating. Cast iron, therefore, when coated with a steel deposit and heat-treated, should give so much carbon to the deposited steel as to make it extremely hard, without further treatment. Thus, in effect, a means of providing cast-iron parts having frictional or other bearing surfaces with a hard homogeneous layer of wear-resisting metal is indicated. Metal-spraying, therefore, is the first step in this process, and by it the usefulness of the metal-spraying pistol will no doubt be greatly enhanced.

Conclusions.

It is clear from these experiments that beneficial results may be expected with sprayed-steel deposits by using dissolved acetylene as the fuel gas in conjunction with an inert gas or deoxidised air as

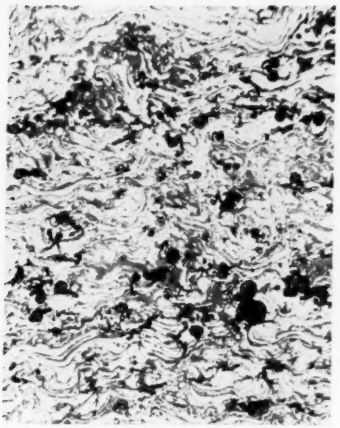

FIG. 1.—0·09% Carbon Steel sprayed with compressed coal gas, using air as impelling medium. Unetched. × 250.

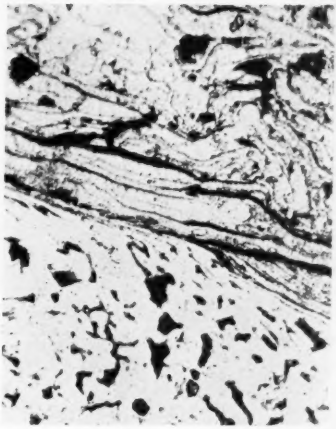

FIG. 2.—0·09% Carbon Steel sprayed with compressed coal gas, using air as impelling medium. Transverse section at junction of deposit and base. Etched. × 250.

FIG. 3.—0·09% Carbon Steel sprayed with compressed coal gas, using air as impelling medium. Formation of oxide layers; direction of flight of particles indicated by arrow. Unetched. × 1300.

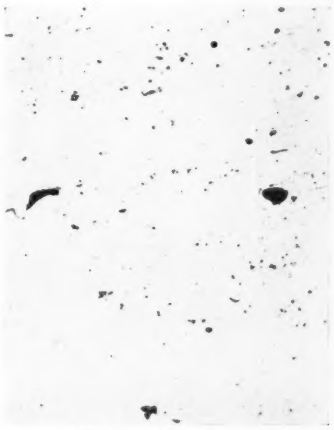

FIG. 4.—0·09% Carbon Steel sprayed with dissolved acetylene, using nitrogen as impelling medium. Unetched. × 100.

(Micrographs reduced to two-thirds linear in reproduction.) [*Sillifant.*

[*To face p.* 136 P.

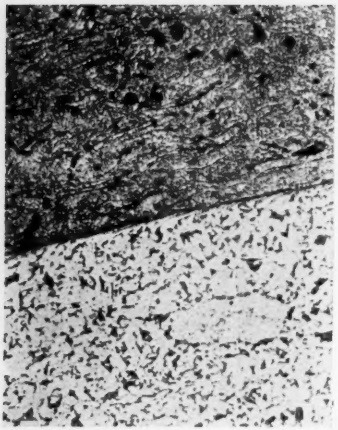

FIG. 5.—0·09% Carbon Steel sprayed with dissolved acetylene, using nitrogen as impelling medium, upon a bar of 0·30% carbon steel. Transverse section at junction of deposit and bar. Etched. × 100.

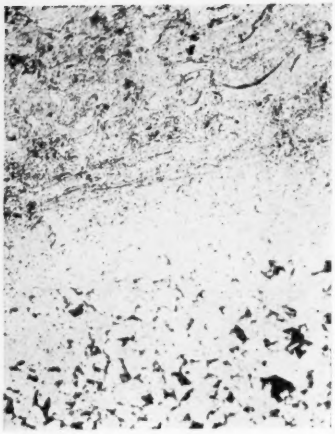

FIG. 6.—Same as Fig. 5, but after heat treatment at 900° C. for 1 hr. Etched. × 100.

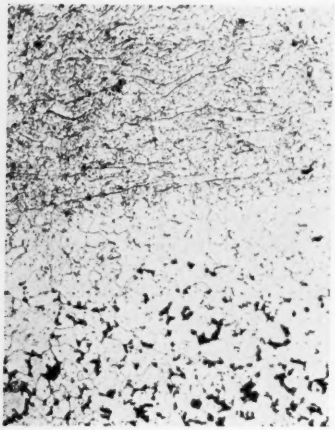

FIG. 7.—Same as Figs. 5 and 6, but after heat treatment at 900° C. for 2 hr. Etched. × 100.

FIG. 8.—Same as Fig. 5. Etched. × 1300.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Sillifant.*

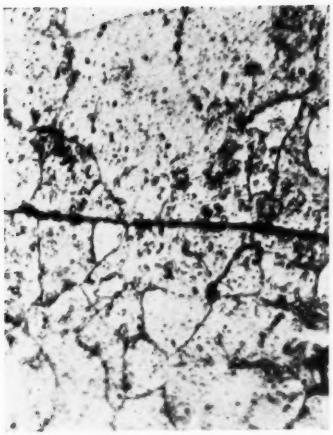

FIG. 9.—0·09% Carbon Steel sprayed with dissolved acetylene, using nitrogen as impelling medium, upon a bar of 0·30% carbon steel. Transverse section at junction of deposit and bar, after heat treatment at 900° C. for 2 hr. (*cf.* Fig. 7). Etched. × 1500 (reduced to two-thirds linear in reproduction).

FIG. 10.—Bar of Mild Steel, $\frac{3}{4}$ in. in dia., 9 in. long, bearing a deposit of $\frac{1}{16}$ in. on the diameter of 0·09% carbon steel, sprayed with nitrogen as the impelling medium. Heat-treated for 1 hr. at 900° C. Bent cold through an angle of 90°.

[*Sillifant*

FIG. A.—Sprayed Mild Steel, by wire process. Note columnar crystals indicated by arrow. × 400.

FIG. B.—Same as Fig. A after heating at 900° C. for ½ hr. Oxide = half-tone. × 400.

(See Rollason's contribution.)

Correspondence on Sillifant's paper.
[*To face p.* 137 P.

the impelling medium, coupled with suitable heat treatment after spraying.

Where steel deposits of high quality are demanded, such as on machine parts subject to heavy varying loads, these methods may prove of assistance when applied by experienced users of the metal-spraying process, although the cost is high, since nitrogen is not used in sufficient quantities at the present time to make its price economic.

Further, the application of these principles to deposits of metals other than steel may, with time, find favour in the metal-spraying industry, because improved mechanical and physical properties can be expected from treated deposits which will widen the scope of the process still further.

ACKNOWLEDGMENTS.

The author must thank the Directors of the British Oxygen Co., Ltd., and Major Williams for allowing publication of this paper, and also Mr. L. Percival, B.Sc., for the micrographs and valuable advice and assistance given.

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CORRESPONDENCE.

(Figs. A and B = Plate XA.)

Mr. E. C. ROLLASON (Birmingham) wrote that the estimation of the excess oxygen left in the air blast during spraying was interesting, but the use of nitrogen in reducing the oxide content of the coatings was not new, and reference should be made to the paper by J. Fassbinder and P. Soulary.[1]

There seemed to be an implication in the paper that annealing sprayed steel "refined" the structure, whereas the writer had never found this effect when dealing with ordinary sprayed steel. In his opinion the major portion of the coating, sprayed under

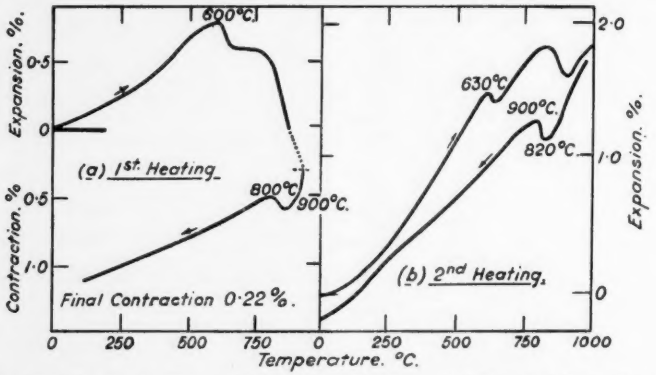


FIG. C.—Expansion Curves of Sprayed Mild Steel. (*a*) First heating. Contraction masks critical points. (*b*) Second heating. Critical points evident.

normal conditions, consisted of saucer-like masses which solidified after striking the article being coated, and consequently formed minute columnar crystals perpendicular to the surface, as shown in Fig. A. Unless suitable etching technique were available, such small crystals were masked by the oxide layers.

Heating caused the agglomeration of the films of oxide and allowed sintering of the adjacent particles to occur, invariably with grain growth, as illustrated in Fig. B. It would, therefore, be interesting to know whether steel sprayed with nitrogen behaved differently from this, and also whether carbon would not diffuse from the core into a coating sprayed with compressed air.

A point not mentioned in the paper was that the sintering of the particles in the coating was always associated with a considerable contraction, as shown by the expansion curves in Fig. C. The contraction, and hence sintering, occurred rapidly above

[1] Twelfth International Congress on Acetylene, Oxy-Acetylene Welding and Allied Industries, 1936, vol. 5, p. 1219.

700° C., and the carbon content seemed to have little effect on this temperature. This was not in agreement with the statement in the paper that a steel having a high carbon content would recrystallise at a lower temperature and in a shorter time. Had Mr. Sillifant any evidence to support his conclusion?

The heat treatment of sprayed coatings of steel at temperatures as high as 900° C. had disadvantages as well as advantages. The volume change mentioned above naturally bound the coating on to a shaft, but would tend to strip a liner from inside a cylinder. Further, the heating of work built up by spraying would be a serious deterent to the use of the process, because the outstanding advantage of this method of salvage was the fact that the operation was carried out without heating the object being treated. Distortion, cracking and other troubles were thus obviated. If such temperatures were permissible, welding would be a preferable method to use in many applications, because the adhesion would be superior. The thick junction line in Fig. 9 might be due to electrochemical attack, but the photograph did not convince one that the adhesion would compete with that produced by welding.

Mr. W. E. Ballard (Dudley) wrote that the author was to be congratulated for bringing before the Institute results obtained in a field of research which had until recently received very little attention. He had shown that sprayed steel under certain conditions would yield to heat treatment and give results which might be extremely valuable in commerce. His results, however, had been obtained by the use of acetylene as the fuel gas and nitrogen as the propelling gas. This was, of course, an ideal combination, but in the writer's experience it was not absolutely necessary to use this method to obtain the results given. To obtain carbon diffusion in the manner described, it was, of course, necessary to reduce the quantity of oxygen in the sprayed coating to a minimum, but this could be achieved in more ways than those outlined in the paper. While the author was fortunate in using the gases mentioned, he carried out his experiments on a $\frac{3}{4}$-in. steel bar rotating in a lathe, which was a method calculated to increase the percentage of oxygen in the coating, as, during half the time, the sprayed metal, hot from the pistol, was away from the nozzle and the protecting effect of the neutral gas zone set up by using nitrogen. Had he used a flat test-piece and some method of keeping the surface in contact with neutral gases, his oxide content might have been even lower and his diffusion more rapid. On the other hand, the writer considered Fig. 1 to be unfair to the coal-gas/air spray, because the photograph showed a state of affairs which should not be allowed. The main factors ruling the oxidation of sprayed metal could be stated as :

(1) Nozzle distance.
(2) Transference of heat from the sprayed layer.
(3) Amount of oxygen used in the flame.

The last factor could not be varied widely while keeping a fine spray, but, nevertheless, it could be varied sufficiently to prevent a good deal of oxidation. Fig. 1 indicated that the amount of oxygen had been excessive.

Nozzle distance had a very great effect, and the smaller this was in practice the less likelihood was there of oxidation. Unfortunately, small nozzle distances brought about a large increase in the temperature of the metal deposited, and therefore, if small nozzle distances were used, the work must be large enough to transfer heat away quickly, or alternatively the test-piece should be cooled. In commerce metal spraying was usually applied to articles of a considerable size and chilling became automatic; therefore a nozzle distance of about 2 in. could be used. Provided that the oxygen fed to the flame was kept as low as possible and the above conditions existed, the final results, even with air as the propellant, were not widely different from those shown in Fig. 4. He was sure the author would not suggest that the commercial coatings usually applied with coal gas and air had the characteristics shown in Fig. 1, and he would, perhaps, therefore forgive the writer if he made this point clear.

AUTHOR'S REPLY.

The AUTHOR, in reply, wrote that, first, with regard to the remarks of Mr. Rollason, he would state that he was aware of the paper by Fassbinder and Soulary, and should have directed reference to it in the paper, but owing to error mention of it was not made. However, on reading that paper carefully, he found that emphasis was laid on the following points:

(1) That more homogenous deposits were obtained with the use of dissolved acetylene as the fuel gas than was the case when compressed coal gas was employed.

(2) That with deposits of certain metals such as stainless steel, mild steel and copper, the homogeneity was improved to a remarkable extent by the use of nitrogen as the impelling medium in place of the compressed air normally employed. Fassbinder and Soulary proved this contention by the inclusion in their paper of micrographs of deposits of various metals made both with compressed air and with nitrogen as the impelling medium.

These findings were in complete agreement with the facts which he found in his own experiments, but he believed that he had taken the argument a step further and had shown the reasons for the superiority of the dissolved-acetylene/nitrogen combination for the spray treatment of ferrous materials. Mr. Rollason asked whether steel sprayed with nitrogen reacted differently when

heated from steel sprayed with air. The answer was that it did, since the sintering of the particles of steel sprayed under normal conditions was hindered by the oxide content. As Mr. Rollason said, the oxide must first agglomerate before sintering of the particles or re-solution of the mass could take place. This agglomeration of oxide coincided with a volume change in the mass which took the form of a contraction, of over 2·5% in some cases. A deposit of steel made with nitrogen, however, reacted to heat treatment in a much more normal manner, since there was less oxide present and the carbon-oxygen reaction was not so marked; in addition, the greater homogeneity of a deposit made with nitrogen also had an effect on the contraction.

There was a further point that he would like to make here. Mr. Rollason's dilation diagrams had, he believed, been obtained on specimens sprayed upon flat surfaces. As there was an initial contraction effect immediately on spraying which would tend to bind the coating to a shaft, relief of the stress set up, which took place on heating, would give a different dilation diagram from the first that Mr. Rollason showed, and would, under normal circumstances, produce a curve more like the one that he had obtained on the second heating in Fig. C. Therefore Mr. Rollason's remarks on the effects of heating did not give an accurate picture of the reaction of steel coatings made on shafts with the dissolved-acetylene/nitrogen combination of gases.

With regard to the carbon content and the effects of heating, he had meant to imply that the higher the carbon content of nitrogen-sprayed steel the lower would be the temperature necessary to effect recrystallisation, since the critical temperature of steel changed with the carbon content. The main point was that steel deposited with nitrogen was more normal than that sprayed with air, and in consequence such deposits would react to treatment more like normal steel.

It was quite correct to state, as Mr. Rollason did, that the advantages of the metal spraying process as applied at the present time lay in the fact that articles being treated were not heated and were therefore not subjected to distortion. It was also correct to say that the use of the methods described in the paper was not to be recommended at this stage in the commercial field of the process, but that a way to the better understanding of the influences acting on sprayed metal was opened up. This would have an important bearing on the subject when study was directed to the production of ferrous alloys in wire form, particularly for use by the metal-spraying pistol, since certain changes took place in the material owing to spray treatment which could be balanced by the use of materials of the desired analysis.

Mr. Ballard's remarks were very interesting and valuable, and his statement that a more normal type of structure could be obtained on a flat plate by the coal-gas/air spray combination was correct.

It was, however, the author's intention to study the type of coating obtained on a shaft. He agreed that a reduction of the nozzle distance would produce better deposits, but it was also liable to cause overheating of the deposited material and all the troubles attendant upon this most unwelcome factor. The cooling of the work was to be recommended in commercial practice if it was carried out with discrimination, but the application of an oxygen-containing air stream on to the warm sprayed metal was a dangerous procedure when attempting to reduce the oxide content of a sprayed deposit.

THE MECHANISM OF NITRIDE-HARDENING.*

By M. S. FISHER, D.Sc., Ph.D., A.R.T.C., and Z. SHAW, B.E., A.R.S.M., D.I.C., M.Sc. (London).

(Figs. 4 to 13 = Plates XI. and XII.)

Summary.

Two Nitralloy steels have been nitrided under various conditions, and the microstructure and hardness of the case have been investigated. From the results the following conclusions have been drawn.

A normally nitrided steel is coated with a "nitride" layer (γ' and ϵ) about 0·03 mm. thick, below which is a duplex zone consisting of γ' and ferrite, the proportion of the former decreasing from the surface inwards. In pure ammonia the nitride layer forms in a few minutes at 500° C. It is brittle and spalls when severely stressed. The γ'–α aggregate is much less brittle.

The generally-accepted explanation of the hardness of nitrided steel (*viz.*, that it is due to "dispersion" hardening caused by submicroscopic particles of alloy nitrides in α-iron) accounts for the main part of the hardening (up to about 850 Vickers) but iron nitride hardened by dispersed alloy nitrides is responsible for the intense hardness close to the surface.

The rate of nitriding is controlled by the rate of diffusion of nitrogen in the steel. The characteristics of the case produced in a given time at a given temperature are largely independent of the composition of the nitriding gas and of the physical condition of the surface of the steel. Once the nitride layer has been formed, the ammonia can be diluted with about 10 times its volume of nitrogen or about one-third of its volume of hydrogen without affecting the efficiency of the process. The hardness of the case is not materially affected by rapid cooling or by ageing at room temperature.

Prolonged annealing of a nitrided steel in nitrogen eliminates the visible nitride, and reduces the surface hardness to about 850. Similar effects are produced more rapidly by heating in hydrogen. The hardness below the surface is raised and the case depth is increased by annealing.

Introduction.

As the general features of the nitriding process are well known, only a brief outline of them will be given here. The process consists in heating a special type of steel in a stream of anhydrous ammonia. The ammonia coming into contact with the surface of the steel dissociates into hydrogen and nitrogen, and a proportion of the latter dissolves in the iron, forming a solid solution of nitrogen in α-iron. When this is saturated, it reacts with more nitrogen to

* Received July 13, 1937.

form a constituent known as γ', which in turn reacts with nitrogen to form another phase, ε.* These two constituents are commonly described as iron nitrides, Fe_4N and Fe_2N respectively, but while the formula Fe_4N corresponds closely to the composition of γ' (5·9% of nitrogen), ε may contain anything from 8·0 to 11·1%, or possibly even more. It is preferable therefore not to use these formulæ, though the general term "iron nitride" is permissible. The microstructure of a cross-section through a piece of nitrided iron, cut at right angles to the nitrided surface, consists of a thin outer layer of ε, below which is a duplex region composed of ε and γ', the latter constituent increasing in amount until a layer composed of γ' alone is reached. This is followed by a second duplex zone consisting of γ' and α, the proportion of the former decreasing progressively as the distance from the surface increases, until the core is reached. Nitriding therefore alters considerably the structure of pure iron, but unfortunately it has little effect on its properties; even in the "nitride" layer, which is the hardest part of the case, the Brinell hardness is less than 200. It is evident therefore that the two nitrides, γ' and ε, are relatively soft.

If however the iron contains elements such as aluminium, chromium and vanadium, the nitrides of which are stable and practically insoluble in α-iron, an intensely hard case is produced by nitriding. The steels generally used for the process are of the type known as "Nitralloy," and contain about 1% of aluminium, 1·5% of chromium, 0·25% of molybdenum, and from 0·2 to 0·6% of carbon depending on the mechanical properties required in the core. The aluminium is responsible for the greater part of the hardening, but the chromium contributes to this too, and also flattens the hardness gradient below the surface, thus reducing the risk of spalling. The molybdenum is added mainly for the purpose of improving the mechanical properties of the core by refining the grain size.

There has been some controversy about the effect of nitriding on the microstructure of Nitralloy steel. According to the literature, the general opinion is that it is mainly unaltered by the process, the only effect universally observed being that the ferrite matrix of the hardened case etches more rapidly than the core, forming a stained rim, the depth of which corresponds roughly to the thickness of the case. Some workers[1,2] have observed a network or scattered needles of a white constituent in the outer part of the case, especially in samples annealed before nitriding and in the decarburised layer at the surface of hot-rolled bars. While this paper was being written, the results of a valuable research by Gunnar Hägg[3] on the structure of nitrided steel were published by the Royal Swedish Institute for Engineering Research. His data were

* There is some evidence that this constituent may finally be converted into another phase, differing only slightly from ε but containing more nitrogen. The data on this point are, however, inconclusive.

obtained by microscopic and X-ray methods, and show that the two nitrides observed in nitrided iron (γ' and ε) are formed also in steels of the Nitralloy type. These nitrides, however, are not generally regarded as essential constituents of nitrided steel, and it is assumed, even by Hägg, that they do not materially affect its hardness. The widely-accepted explanation of the hardness of the case is that it is due to " dispersion " or " precipitation " hardening, caused by sub-microscopic particles of aluminium nitride and chromium nitride dispersed through the α-iron matrix of the steel. The main objects of the present investigation were (*a*) to test the above hypothesis, (*b*) to find whether iron nitride is a normal constituent of nitrided steel, (*c*) to study the mechanism of nitriding, and (*d*) to find whether the process could be speeded up by modifying the nitriding conditions, particularly by some preliminary treatment of the surface of the steel.

Materials.

Two Nitralloy steels of the composition given in Table I. were used. They differ essentially only in carbon content, and for the convenience of the reader they have been allotted numbers (*C*3 and *C*5) representing approximately the percentage of this element in each.

Table I.

Steel No.	C. %.	Al. %.	Cr. %.	Mo. %.	Ni. %.	Si. %.	Mn. %.
*C*3 . .	0·28	1·08	1·60	0·41	(0·25)*	(0·35)	(0·65)
*C*5 . .	0·53	1·36	1·67	0·29	0·25	0·24	0·68

* Figures in brackets are according to the makers' specifications.

Steel *C*3 was used as supplied by the makers, in the " heat-treated " condition, *i.e.*, oil-quenched from 900° C. and tempered at 650° C. (Vickers hardness 250). Its microstructure consisted of small islands of ferrite in a matrix of ferrite containing minute carbide globules. As the steel had obviously been quenched at a temperature inside the critical range, it was thought advisable to check the makers' treatment. A sample was therefore rehardened and tempered at the above temperatures, but the structure was found to be unchanged. As this is the condition in which the steel is employed commercially, it was decided not to try to make its structure more homogeneous by changing the heat treatment. Steel *C*5 was supplied in the softened condition (Vickers hardness 232) ready for machining. Its structure consisted of minute carbide globules uniformly distributed through a matrix of ferrite (*cf.* Fig. 12). To improve the mechanical properties of the core, the steel would normally be hardened and tempered by the user before nitriding, producing a structure of essentially the same type but

finer. As this investigation was not concerned with the properties of the core, the steel was nitrided as received from the makers.

Apparatus.

The specimens to be nitrided were placed on a perforated aluminium tray midway between the ends of a silica tube (3 ft. long, and 2 in. in internal dia.) which formed part of an electrical resistance furnace. Each end of the tube was closed by a rubber bung, bored with two holes, one for a chromel-alumel thermocouple enclosed in a pyrex sheath, and the other for a short glass tube which served as the gas inlet or outlet. One of the thermocouples was connected to a temperature recorder, and the other to a Cambridge thermo-electric temperature regulator by means of which the temperature during nitriding was maintained at $500 \pm 3°$ C.

The gas for the ordinary nitriding experiments was obtained from a cylinder of anhydrous ammonia, which was connected to the nitriding furnace through a train of drying towers. The waste gas from the furnace was passed through a gas burette, which was used for measuring the percentage dissociation of the ammonia, and was then bubbled through about an inch of water, so as to maintain a slight pressure in the apparatus. As the arrangement of the dissociation burette was substantially similar to that normally used for the purpose, it need not be described.

Preparation of Specimens.

The steels were obtained in the form of $\frac{3}{4}$-in. round bars, and the method of preparing a specimen was as follows. A short cylinder, about $\frac{1}{2}$ in. high, was sawn from the bar, and all its surfaces were ground on an alundum wheel and roughly finished on emery cloth. One of the flat ends of the cylinder was normal to its axis, but the other was ground at an angle of slightly less than 90°, making a taper of about 0·5 mm. across the surface. This was done so that when the specimen was later reground obliquely, for the purpose of measuring the hardness gradient in the nitrided case, the new surface was roughly parallel to the stage of the testing machine. The taper-ground surface was carefully rubbed by hand on a series of Hubert emery papers, finishing with No. 000, after which the specimen was cleaned in Westrosol oil and benzene.

Nitriding Procedure.

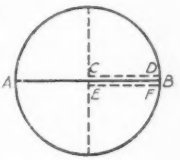
In each experiment, 3 or 4 specimens were arranged on the tray in the nitriding furnace, with the prepared surface up. The rubber bungs were fitted into the ends of the tube, and the joints sealed with acetone collodion. When this was dry, the ammonia was turned on, rapidly at first till all the air in the tube had been displaced, *i.e.*, till the gas leaving the furnace was 100% ammonia,

which required normally about 15 min. When the nitriding reagent was not pure ammonia, the gas was allowed to flow rapidly for about 45 min. to make certain that all the air had been eliminated. The rate of flow was then reduced to the required value, which was measured approximately by counting the number of bubbles per minute in the water-bottle used for maintaining the pressure in the apparatus, and checked at intervals by means of the dissociation burette. In all the experiments, the rate of flow corresponded to 15% dissociation when nitriding with pure ammonia.

After nitriding for the required length of time, the heating current was switched off, but the gas stream was maintained and the specimens were left in the furnace till about 3 hr. later, when they were cold enough to handle.

Construction of Depth-Hardness Curves.

Depth-hardness curves (*i.e.*, curves showing the hardness gradient below the nitrided surface) were constructed by regrinding the oblique face of the specimen at a small angle to its surface, and measuring the hardness along the direction of the taper. The optical method described below was devised for measuring the depth below the original surface at which each hardness determination was made. It utilised a microscope with a graduated focusing device, each division of which corresponded to a vertical movement of 0·002 mm., and a moving stage fitted with a vernier reading to 0·1 mm.



By means of a knife and a ruler, a light scratch was drawn on the oblique face of the specimen, passing through the centre of the surface and the highest point on its periphery; it is indicated by *AB* in Fig. 1. The specimen was then placed on a glass slide which was clamped to the stage of the microscope, with the scratch parallel to the movement of the stage. The scratch was then focused at every millimetre along its length, noting the reading of the focusing knob at each point. This was then plotted against the stage readings, thus obtaining a curve representing accurately the contour of the nitrided surface in the plane of the scratch; the upper curve in Fig. 2 is an example. As will be seen, the surface of the specimen was distinctly curved, and the corners were somewhat rounded. The specimen was then reground in such a way that the portion above the dotted line in the side view in Fig. 1 was removed. A steeper taper than necessary was avoided because it would reduce the accuracy of the resulting depth-hardness curve, and the maximum depth exposed was generally only about 0·6 mm. In experiments

Fig. 1.

that produced an unusually thick case, the surface was of course ground at a sufficient angle to expose the full depth of the case. This new surface was now finished off on Hubert emery papers, and two parallel lines (*CD* and *EF* in Fig. 1) were drawn on it in ink, marking a region directly in extension of the remaining part of the original scratch *AB*. The specimen was then replaced on the microscope stage, and the scratch and the surface between the inked lines were re-focused. A new curve was then plotted as before, and was superimposed on the former one, as shown in Fig. 2. The distance between these curves represents the thickness of the

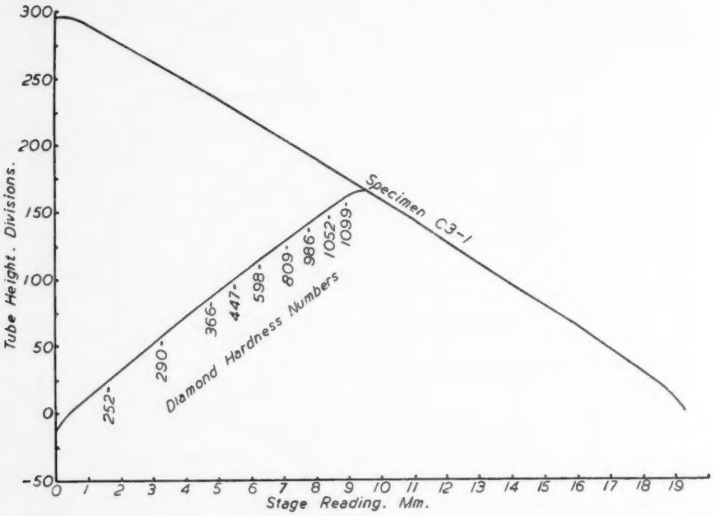


FIG. 2.

layer of metal removed, the experimental error being estimated at $\pm$ 0·003 mm.

Hardness measurements were then made at numerous points in the area bounded by the inked lines, using a Firth Hardometer with a standard 136° diamond pyramid and a load of 30 kg. In parenthesis it may be pointed out that the hardness readings do not represent strictly the hardness of the actual surface tested, because an impression corresponding to a hardness of, say, 1000 Vickers is approximately 0·02 mm. deep. Allowing for the fact that the bulk of the volume of the impression is much closer to the surface than this, it may be said that the readings represent approximately the average hardness of a layer of metal about 0·01 mm. thick. If the hardness gradient in the case were very steep, this would introduce

a serious error into the determinations, but the actual gradient in normally nitrided steel is relatively flat, and the error due to this cause is only about 25 Vickers, which may be regarded as negligible, particularly as the direction of the error is constant, all the readings being low by this amount or less.

Finally the specimen was re-examined with the microscope. The distance of each impression from the edge of the specimen was noted and recorded on the contour graph (Fig. 2). This supplied all the data required for constructing the depth-hardness curve of the specimen, which was done by plotting the hardness numbers against the measured distance between the two contour curves at the points corresponding to the hardness impressions.

Experimental.

The depth-hardness curves of the two steels, *C*3 and *C*5, nitrided in anhydrous ammonia at 500° C. for periods ranging from 24 to

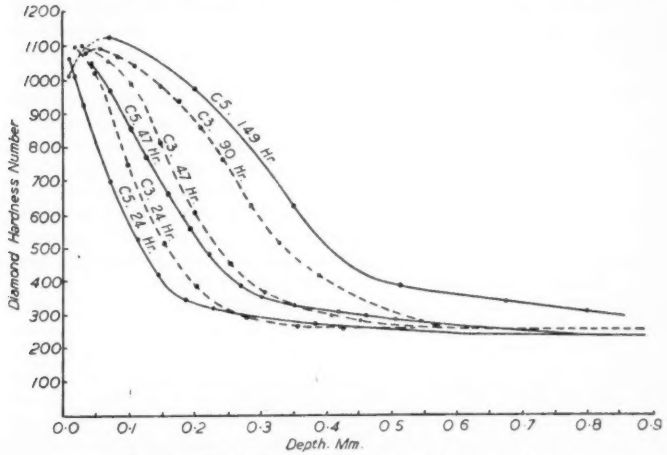


Fig. 3.—Steels *C*3 and *C*5, nitrided in ammonia.

149 hr., are shown in Fig. 3. As mentioned earlier, 3 specimens of each steel were nitrided simultaneously in each experiment. The depth-hardness curve of each of the 3 specimens was determined, and, except in some special experiments to be described later, they invariably coincided most satisfactorily. The authors regard this as a verification of the accuracy of their method of determining the curves.

It will be noted that some of the curves in Fig. 3 differ from those published by most workers in that they do not exhibit a

maximum at a depth just below the surface of the steel. It is usually said that the actual surface of a nitrided steel is relatively soft, and that the maximum hardness is attained some distance below the surface. In the opinion of the authors this is not so. As will be shown later, the surface of a nitrided steel is covered with a layer of iron nitrides (ε and γ') about 0·03 mm. thick, which is so brittle that it cracks and spalls when diamond impressions are made in it. Fig. 5, for example, shows particularly bad spalling round two hardness impressions in the nitride layer in the upper part of the nitrided case of steel *C*3. The spalling is not usually so bad as this, but it is generally serious enough to account for the relatively low readings obtained in this region of the case. The bottom impression in Fig. 5 is in the γ'–α aggregate, which appears to be harder than the nitride layer because this aggregate does not collapse under the load, and therefore gives dependable readings. Owing to the unreliability of the readings made in the nitride layer, the first point recorded on most of the depth-hardness curves in this paper corresponds to a depth of about 0·03 mm., which is generally just inside the γ'–α region. Where readings inside the brittle layer are shown, the corresponding part of the curve is shown in broken line.

The curves in Fig. 3 show that the depth of the case in either steel increases with time, and that for a given time of nitriding a deeper case is formed in the lower-carbon steel, *C*3, than in *C*5—this agrees with the general belief that carbon retards nitriding. It will be noted also that the curves for either of the steels are approximately parallel up to a hardness of nearly 900 Vickers, but that this relationship does not hold for the harder part of the case. This agrees with the evidence that will be put forward later showing that the great hardness of the outer part of the case is due to a factor that only begins to make its effect noticeable at the level in the specimen where the hardness reaches 900 Vickers.

The Microstructure of Nitrided Steel.

After determining the depth-hardness curves, the specimens were prepared for microscopic examination by polishing the tapered surface on paper with magnesium oxide suspended in paraffin.

Fig. 4 represents the structure of steel *C*5 nitrided for 149 hr., etched with a 1% solution of nitric acid in alcohol. Right at the surface of the specimen (the top of the photograph) is a thin white layer (actually about 0·005 mm. thick) which according to the data in the paper by Gunnar Hägg[3] is ε. Below this is a speckled region consisting of an aggregate of this phase and γ', followed by a zone, about midway between the top and bottom of the micrograph, consisting essentially of γ' alone. At high magnification, the structure of this constituent resembles that of martensite, as is shown by Fig. 6. This is a consequence of the way in which the iron

nitride replaces the ferrite matrix of the steel, *viz.*, by growing into the ferrite in needles and lamellæ parallel to some crystallographic direction in the α-iron. The Widmanstätten structure formed in this way remains visible, though rather vaguely, even when the ferrite has been converted completely to the new phase. The grain boundaries in this layer are outlined more or less completely by a dark-etching constituent (*cf.* Fig. 6). This phase was investigated by Hägg, but no conclusion as to its composition was reached.

At a depth of about 0·03 mm. α begins to appear and rapidly increases in amount. Fig. 8 shows the needle-like structure of the γ'–α aggregate at a depth of about 0·05 mm. The α-iron is darkened by the etching reagent (alcoholic nitric acid) and the nitride remains white. Fig. 9 shows the same area of the specimen after etching for a few minutes with a boiling solution of sodium picrate, which stains the iron nitride and leaves the ferrite white. At greater depths the proportion of γ' decreases rather rapidly, and it is soon confined mainly to intergranular films, as is shown by Fig. 10, which illustrates the structure at a depth of 0·2 mm., etched with sodium picrate. In Fig. 11 (depth 0·3 mm.) the same type of structure, but with rather less γ', is shown etched with nitric acid. The structure is similar to that of the unaltered core (Fig. 12, depth 0·6 mm.) except that the ferrite-carbide matrix there is not darkened to the same extent, and contains no visible iron nitride.

If the above description is compared with the depth-hardness curve of the specimen (Fig. 3, steel *C*5 nitrided 149 hr.), it will be found that although the maximum hardness corresponds to a level where the structure contains a considerable proportion of γ', the hardness does not drop off so rapidly as the proportion of iron nitride does—even at a depth of 0·3 mm., where there is little nitride to be seen, the hardness is still over 700 Vickers. The hardness of the steel at this level is clearly not due to the visible iron nitride.

All the structures described above were observed also in the specimens of steel *C*5 which had been nitrided for 24 and 47 hr., the only difference being that the various layers were correspondingly thinner. The same general sequence of structures was formed also in the nitrided specimens of steel *C*3, as a comparison of Figs. 4 and 5 will show. There were, however, some minor points of difference between the two steels. For example, the carbide globules in the tempered matrix of steel *C*3 were smaller, and the nitride layer (ε and γ') formed in a given time was slightly thicker than in the other steel, *e.g.*, 0·035 mm. in steel *C*3 after 90 hr., as against 0·03 mm. in *C*5 after 149 hr. As was mentioned earlier, there were small islands of free ferrite in the structure of the lower-carbon steel, but these did not seem to have any appreciable effect on the behaviour of the steel, or on the distribution of the iron nitride. Fig. 7, for example, shows the structure of this steel nitrided for 90 hr., at a level just below the unspalled diamond impression in Fig. 5. The

specimen was etched slightly with nitric acid to develop the structure of the matrix, and then with sodium picrate to darken the γ'. It will be seen that the nitride needles are scattered indiscriminately through the white ferrite islands and the tempered matrix of the steel.

The Mechanism of Nitriding.

In the light of the evidence described in the preceding section, which is essentially in agreement with the conclusions reached by Hägg by microscopic and X-ray methods, it is possible to form a picture of what probably happens during nitriding.

When the Nitralloy steel is heated in ammonia, the nitrogen liberated by the decomposition of the gas dissolves in the surface of the steel and diffuses away inwards. When the dissolved nitrogen comes in contact with atoms of aluminium and chromium, which are distributed at random through the iron lattice, it combines with these elements forming nitrides, AlN and CrN, which are insoluble in α-iron, and are precipitated as sub-microscopic particles. This uses up nitrogen, which continues to dissolve at the surface and to diffuse into the metal. In a short time, apparently only a few minutes, as will be shown later, practically all the aluminium and chromium in the metal right at the surface has been precipitated. The α-iron there now becomes saturated with nitrogen, and the saturated solid solution reacts with more of this element to form the lower nitride, γ'. This constituent in turn becomes saturated with nitrogen at its surface, and reacts with it to form the higher nitride, ε. Nitrogen is able in some way to penetrate these nitrides, slowly forming more ε at the expense of the underlying γ', and more rapidly γ' at the expense of the underlying α, with the result that the layers of the two nitrides become progressively thicker. Nitrogen is supplied continuously by the γ' to the α-iron adjacent to it. At the interface between these two phases, the α-iron is kept saturated with nitrogen, which diffuses away continuously from there into the interior, precipitating the aluminium and chromium as nitrides during its progress. Countless particles of these compounds, so small as to be invisible at the highest magnification, are scattered throughout the α-iron, and when this phase is later converted into iron nitride, the distribution of the aluminium and chromium nitrides is apparently quite unaltered. The dispersed alloy nitrides cause dispersion-hardening of the α-iron and of the iron nitrides too.

For the reason explained in a later section it appeared to the authors that the above hypothesis (which is really just an amplified version of the prevailing view as to the mechanism of the process) could be tested by annealing nitrided specimens in an inert atmosphere and in hydrogen, and also that it should be possible to find out in the same way whether the iron nitride has any effect on the hardness of the steel; the prevailing opinion is that it has none.

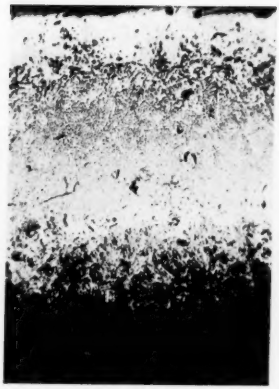


FIG. 4.—Steel *C5*, nitrided 149 hr. Upper part of case. Etched in alcoholic nitric acid. × 100.

FIG. 5.—Steel *C3*, nitrided 90 hr. Upper part of case. Etched in alcoholic nitric acid. × 40.

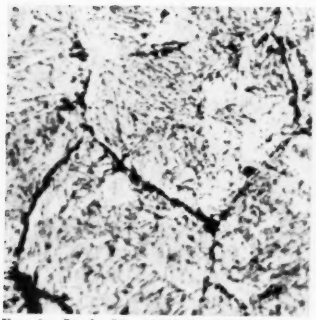


FIG. 6.—Steel *C5*, nitrided 149 hr. γ' + unknown constituent (+ Fe_3C). Etched in alcoholic nitric acid. × 1000.

FIG. 7.—Steel *C3*, nitrided 90 hr. γ', free ferrite, and ferrite-carbide matrix. Etched in sodium picrate and alcoholic nitric acid. × 1000.

[*Fisher and Shaw.*
[*To face p.* 152 P.

FIG. 8.—Steel *C5*, nitrided 149 hr. $\gamma' + \alpha$ ($+Fe_3C$). Etched in alcoholic nitric acid. × 1000.

FIG. 9.—Steel *C5*, nitrided 149 hr. $\gamma' + \alpha$ ($+Fe_3C$). Etched in sodium picrate. × 1000.

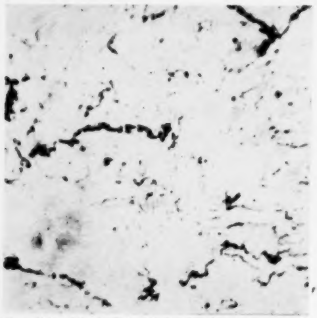


FIG. 10.—Steel *C5*, nitrided 149 hr. $\alpha + \gamma'$. Etched in sodium picrate. × 1000.

FIG. 11.—Steel *C5*, nitrided 149 hr. $\alpha + \gamma' + Fe_3C$. Etched in alcoholic nitric acid. × 1000.

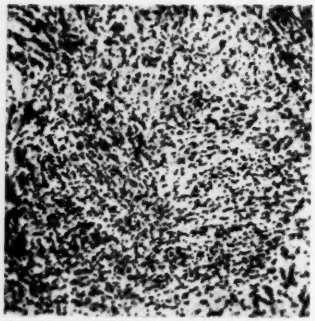


FIG. 12.—Steel *C5*, nitrided 149 hr. Core. $\alpha + Fe_3C$. Etched in alcoholic nitric acid. × 1000.

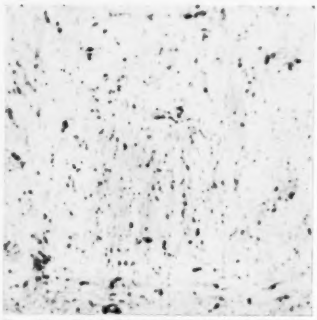


FIG. 13.—Steel *C5*, nitrided 47 hr., annealed 197 hr. $\alpha + \gamma'$ ($+Fe_3C$). Etched in sodium picrate. × 1000.

[*Fisher and Shaw.*

[*To face p.* 153 P.

The Effect of Annealing Nitrided Steel in Nitrogen.

As molecular nitrogen does not react with steel at 500° C., the experiments described below, in which nitrided steels were reheated to this temperature in nitrogen, may be regarded simply as annealing experiments carried out in an inert atmosphere.

Samples of steel *C*5 were nitrided for 24 and 47 hr., and then annealed in nitrogen for various periods up to 197 hr. The depth-hardness curves obtained after these treatments (Fig. 14) show that annealing for 24 hr. slightly reduced the surface hardness of the specimen that had previously been nitrided for 24 hr., and materially

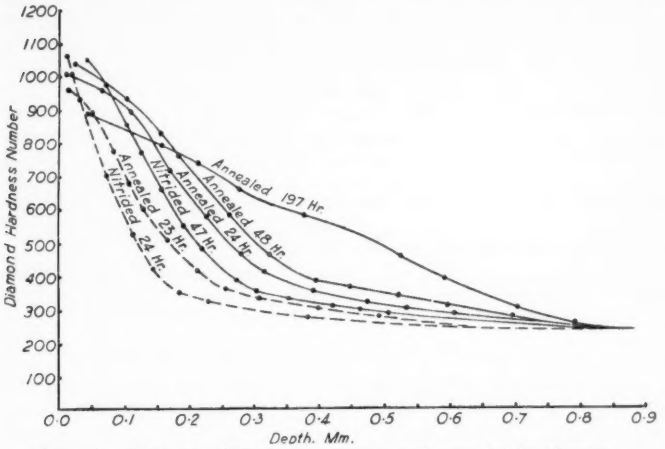


Fig. 14.—Steel *C*5, nitrided in ammonia and annealed in nitrogen.

increased the depth of the case, though this increase was smaller than that caused by continuing the nitriding for the same period, *i.e.*, by nitriding for 47 hr.

Similar results were obtained by annealing after the longer nitriding treatment. In 24 hr. the hardness close to the surface was slightly reduced, while the depth of the case was increased. After 47 hr. the surface hardness had risen slightly, but the increase in the depth of the case had continued. After 197 hr. the hardness at the surface had fallen to just below 900 Vickers, and the case had become considerably thicker. It will be observed that the effect of prolonged annealing on the nitrided steel was to increase the hardness of the part of the case that was originally softer than about 850 Vickers, and to reduce the hardness of the upper part of the case towards this value.

The annealed specimens were examined microscopically, and it

was found that no marked change had been caused by annealing for 24 or 47 hr., except that the part of the case that had originally consisted of an aggregate of γ' and α, rich in the former, etched less vigorously than before, no doubt because of a reduction in the heterogeneity of the structure there, caused by many of the finer needles of iron nitride dissolving in the adjacent α-iron. The justification for this suggestion lies in the fact that prolonged annealing eliminated nearly all the iron nitride. In the specimen that had been annealed for 197 hr., the nitride layers were no longer discernible, and from the surface inwards the structure appeared to consist of α-iron containing small specks of iron nitride, and carbide globules. Fig. 13 shows the microstructure of the specimen (etched deeply with sodium picrate) at a depth of about 0·05 mm. below the surface, where the structure was originally similar to that illustrated in Fig. 9. The darker specks in Fig. 13 are probably iron nitride, but some of the very faint ones may perhaps be Fe_3C. Very close to the surface of the annealed specimen, the steel etched rather more rapidly than further in, and the grain boundaries were very conspicuous, more so than in Fig. 6. These effects may have been due to oxygen penetrating into the steel (the specimen was slightly blued despite the steps taken to deoxidise the nitrogen) or possibly, in part at least, to an increase in the amount of the unknown constituent seen in Fig. 6.

The interpretation of the results of the annealing experiments will be discussed at the end of the next section.

The Effect of Heating Nitrided Steel in Hydrogen.

Specimens of steel *C*3 were nitrided for 47 hr. in ammonia and then reheated at 500° C. for 24 and 49 hr. respectively in a stream of hydrogen. It was found that the waste gas from the furnace soon became contaminated with ammonia, which showed that the iron nitride in the steel was being reduced by the hydrogen, forming iron and ammonia. The depth-hardness curves for the hydrogen-treated specimens are shown in Fig. 15 along with the curve for the original nitrided steel. It will be seen that 24 hr. treatment in hydrogen had the same general effect as prolonged annealing in nitrogen. The hardness of the upper part of the case was reduced to slightly below 900 Vickers, and there was a small increase in the depth of the case. No appreciable change in the hardness at any depth was caused by continuing the treatment 25 hr. longer.

The effect of the hydrogen treatment on the microstructure of the steel was also similar to that of long annealing in nitrogen. It eliminated the nitride layers, replacing them by α-iron. One conspicuous difference was that a network of intercrystalline cracks was developed by the hydrogen treatment in the part of the case that corresponded to the original nitride layers. These cracks were no doubt caused by the shrinkage that accompanies the

reduction of iron nitride to α-iron; α-iron has a density of 7·88, γ' 7·11, and ε 6·88.[4] The absence of similar cracks in the nitrogen-

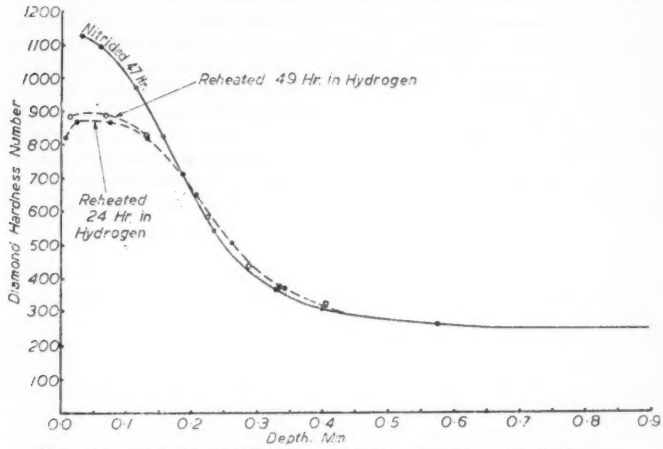


FIG. 15.—Steel *C*3, nitrided in ammonia and reheated in hydrogen.

annealed specimens was probably due to the different mechanism of the change, and to the slowness with which it takes place.

CONSIDERATION OF THE RESULTS OF THE REHEATING EXPERIMENTS.

The effect of reheating, whether in hydrogen or in nitrogen, is virtually to reverse the nitriding reactions between iron and nitrogen, removing any "unfixed" nitrogen (*i.e.*, nitrogen not combined with aluminium and chromium) from the steel. In the hydrogen treatment the nitrogen is removed mainly from the surface by reacting with the hydrogen, but it is also removed partly by inward diffusion from the vicinity of iron nitride in the direction of the core. The former process is exactly analogous to the decarburising of steel by hydrogen at a high temperature and need not be discussed, but the mechanism and effect of the inward diffusion require comment, especially as this is the main reaction that takes place in the steel when annealed in an inert atmosphere. At any time during annealing, the α-iron in contact with iron nitride is saturated with nitrogen, but this element diffuses continuously away into the unsaturated α remote from the contact, *i.e.*, in the general direction of the core. This tends to reduce the nitrogen concentration in the α-iron at the γ'–α interface, and as the nitride there can only exist in contact with saturated α, it must

continue to supply nitrogen to this phase. It can do this only by decomposing at the interface into iron and nitrogen, or in other words by "dissolving" in the adjacent α-iron in exactly the same way as the excess cementite in a hypereutectoid steel dissolves in the unsaturated austenite when the steel is heated above the eutectoid temperature. The result of the inward diffusion during annealing is therefore that the γ' recedes towards the surface, whereas during nitriding it advances towards the core. In the same way, and for the same reasons, the lower limit of the ε layer also recedes towards the surface. The final result, if the annealing is sufficiently prolonged, is that all the iron nitride is eliminated. The same result is produced in much less time by heating in hydrogen than in nitrogen, because in the former case the nitrogen is removed rapidly from the surface too.

The nitrides of aluminium and chromium, however, are stable, even in the presence of hydrogen,[5] and insoluble in α-iron, and therefore should not be affected by annealing. If therefore the hardness of nitrided steel is due to finely-dispersed alloy nitrides in the α-iron, as is generally supposed, it should not be reduced by annealing. In fact, as far as the properties of the nitrided steel are concerned, the only effect of reheating should be an increase in the depth of the case, caused by the nitrogen liberated by the decomposition of the iron nitride diffusing inwards during the treatment, precipitating aluminium and chromium nitrides. As was pointed out in describing the depth-hardness curves, this increase in the case depth does take place (*cf.* Figs. 14 and 15); the effect is much more pronounced when the annealing is done in nitrogen than in hydrogen, because in the latter treatment all the free nitrogen is rapidly extracted by the hydrogen from the surface of the steel, and thereafter it diffuses outwards at least as rapidly as inwards.

The curves show, however, that in the hardest part of the case, where iron nitride was originally an important constituent of the microstructure, the hardness was reduced by prolonged annealing in nitrogen, or by a relatively short treatment in hydrogen, to a value of about 850 Vickers; this change was accompanied by the elimination of most of the visible nitride from the structure. In that part of the case, however, where the hardness was originally below about 850, and where the steel originally contained little visible iron nitride, annealing in hydrogen had no material effect, while the same treatment in nitrogen decidedly increased the hardness. This evidence suggests that in nitrided steels, hardness up to about 850 Vickers is due solely to dispersion-hardening of the α-iron by precipitated alloy nitrides, but that in the upper part of the case the additional hardness is due to the iron nitride there, hardened like the α-iron by dispersed alloy nitrides; when the iron nitride is removed, and converted to α-iron, the hardness falls to about 850.

The interpretation of the annealing experiments was com-

plicated somewhat by the effects produced by the diffusion of nitrogen from the upper part of the case inwards during the treatment. It was evident that the decreased hardness near the surface was caused by the removal of nitrogen, but some doubt remained as to whether the hardness of the lower part of the case would not also have fallen if this part of the steel had not been supplied with additional nitrogen during annealing. To settle this point two nitrided specimens were taper-ground in the usual way, and their depth-hardness curves were determined by taking hardness readings on the tapered surface. The specimens were then annealed for 24 hr., one in nitrogen and the other in hydrogen, and the hardness at

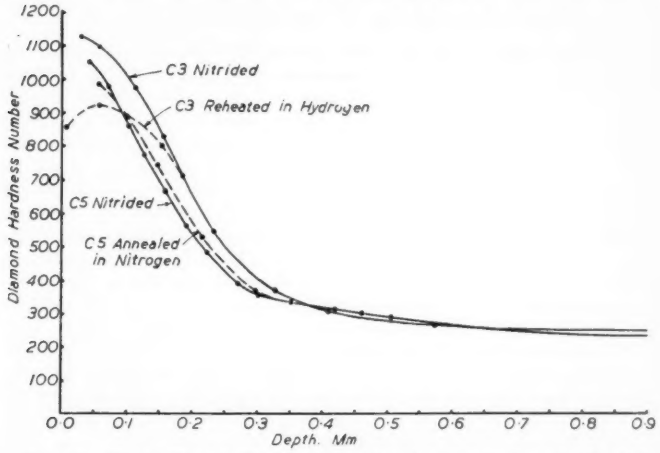


FIG. 16.—Steels *C*3 and *C*5, nitrided 47 hr., taper-ground, and reheated in nitrogen or hydrogen.

various points along the tapered surface was again measured. This procedure eliminated the effects produced by nitrogen diffusing inwards from the outer part of the case, because this had been removed before annealing. Some lateral diffusion would no doubt occur, but its effects would be small, because the concentration gradient below the taper-ground surface would be much steeper than along it. The surface of the nitrogen-annealed specimen had to be cleaned up by polishing it lightly on fine emery paper before re-measuring its hardness. This was found to remove a thickness of 0·002 mm., and an allowance was made for this in plotting its curve. The other specimen did not require polishing.

The results of this experiment are shown in Fig. 16, from which it will be seen that the hardness of the case was reduced, though to only a slight extent in the specimen annealed in nitrogen (because

of the short duration of the treatment) and that the softening was confined to the part of the tapered surface where the hardness was originally over about 850 Vickers. Over the rest of the surface, where there was originally little iron nitride in the structure of the steel, the hardness changes were negligible; the slight increase in the hardness of the specimen annealed in nitrogen may have been caused by lateral diffusion, but the difference is so small that it may be due to experimental error. These results confirm the view expressed above, that in nitrided steel, hardness up to 850 Vickers is due solely to precipitated particles of the stable nitrides of aluminium and chromium dispersed through the α-iron.

The Composition of the Nitriding Gas.

If anhydrous ammonia were heated in contact with steel at 500° C. and at atmospheric pressure for a sufficient length of time to allow equilibrium to be reached, it would decompose almost completely into nitrogen and hydrogen, only 0·129% of ammonia being left in the gas mixture.[5] In the nitriding process, therefore, if the ammonia were passed slowly enough through the nitriding chamber, the gas leaving the furnace would be a mixture of hydrogen and nitrogen, roughly in the proportion of 3 to 1, containing only this small amount of undissociated ammonia. The usual practice, however, is to adjust the rate of flow of the gas so as to leave not less than 70% of undissociated ammonia in the waste gas, because it is found that if the outgoing gas contains appreciably less than this amount, the depth of the nitrided case produced in a given time decreases. It is evident therefore that a large proportion of the ammonia used does not take part in the chemical process, but merely acts as a mechanical sweeper, carrying out of the furnace the mixture of hydrogen and nitrogen formed by the dissociation of a small proportion of the ammonia.

The experiments described below were carried out with the purpose of finding out why this large excess of ammonia is necessary, and how the process is affected by the presence of the nitrogen and hydrogen in the nitriding gas.

The Effect of Diluting the Ammonia with Nitrogen.

Nitrogen from a cylinder, freed from oxygen by means of copper gauze heated to 600° C., was passed over aqueous ammonia contained in a 2-litre bottle, and then through a drying train to the furnace. It picked up an amount of ammonia that depended on the concentration of the ammonia solution, the velocity of the gas stream, and the temperature of the solution. The last two factors were maintained constant, and the concentration of the solution was adjusted to give the required percentage of ammonia in the gas mixture. This was measured by determining the concentration of ammonia in the waste gas from the nitriding

furnace by means of the dissociation burette. It was found that the composition of the gas remained satisfactorily constant during each run. Four different concentrations of the ammonia solution were used; the data are given in Table II.

TABLE II.

Specific Gravity of Aqueous Ammonia.	Percentage of Ammonia in Waste Gas.
0·932	16·0
0·970	7·5
0·977	5·5
0·985	3·5

The depth-hardness curves obtained by nitriding steel *C*5 for 24 hr. and *C*3 for 47 hr. in these gas mixtures are shown in Fig. 17,

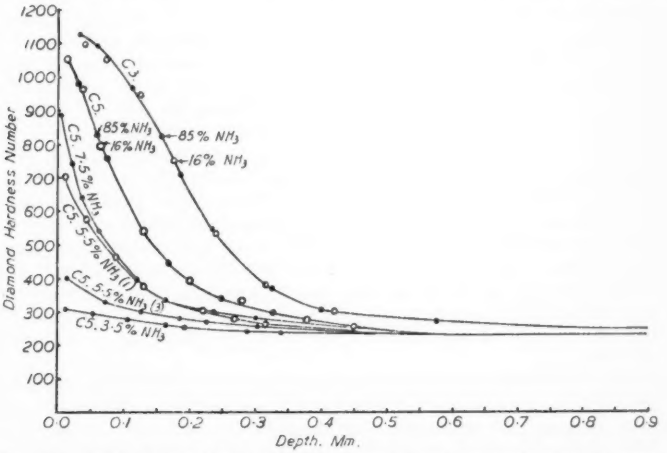


FIG. 17.—Steel *C*3, nitrided 47 hr. in ammonia, and ammonia plus nitrogen. Steel *C*5, nitrided 24 hr. in ammonia and ammonia-nitrogen mixtures.

along with curves for the same steels nitrided under the same conditions in anhydrous ammonia (85% ammonia in the waste gas). These experiments were carried out before the automatic temperature regulator was installed, so the furnace had to be hand-controlled by means of a sliding rheostat. This, however, was done accurately enough to avoid any noticeable discrepancies in the curves.

The 3 specimens of steel *C*5 which were nitrided together in the mixture obtained by passing nitrogen over aqueous ammonia of 0·932 sp. gr. (concentrated ammonia diluted with an equal volume

of water) all gave identical depth-hardness curves, one of which is shown in Fig. 17. As will be seen, this curve coincides closely with that obtained by nitriding in anhydrous ammonia; this applies also to steel *C*3 nitrided for 47 hr. in the same atmosphere. It is evident therefore that the presence of about 80% of nitrogen in the nitriding gas does not in any way impair its efficiency.

When the aqueous ammonia was further diluted, however, the results obtained were definitely inferior. The hardness and depth of the case decreased progressively as the percentage of ammonia in the gas decreased, and, moreover, the hardness attained depended on the position of the specimen in the furnace (*cf.* curves in Fig. 17 for 5·5% ammonia, first and third specimens).

The Effect of Hydrogen in the Gas Mixture.

As it has been found that excess nitrogen in the nitriding gas does not affect the efficiency of the process, the effect of hydrogen could have been studied by using anhydrous ammonia, and adjusting the rate of flow of the gas so as to produce any required degree of dissociation. To obtain a high percentage dissociation, corresponding to a large proportion of hydrogen in the mixture, it would, however, have been necessary to pass the gas very slowly through the furnace, and there might have been some doubt as to whether the results were affected by stagnancy in the gas. In these experiments therefore the hydrogen and ammonia were obtained from commercial cylinders, and the mixture was passed through the furnace at the usual speed. In order that the rate of flow of each gas should be under control, they were bubbled through light lubricating oil before being mixed and dried in the usual train. The composition of the mixture was varied as required by adjusting the relative speed of the two gases, and was measured by determining the percentage of ammonia in the waste gas with the dissociation burette.

Fig. 18 shows the depth-hardness curves obtained by nitriding steel *C*3 in anhydrous ammonia (85% ammonia in the waste gas) and in ammonia-hydrogen mixtures, for 24, 47 and 90 hr. The curves for the 24-hr. treatment show that the mixture containing 25% of ammonia hardened the steel to only a slight extent, and that even the 68% mixture was distinctly less efficient than anhydrous ammonia. Similarly, the treatments lasting 47 and 90 hr. in ammonia-hydrogen mixtures containing 64–66% of the former, produced a thinner case than was developed in the same time in the pure gas. It will be observed that, disregarding the part of the curves where the hardness is above 900 Vickers, the general effect of reducing the ammonia content of the nitriding gas to about 65% was to reduce the depth of case, measured at any given hardness level, by about 0·04 mm., the decrease being practically independent of the nitriding time.

It has been shown above that in the normal nitriding process the steel becomes coated with a thin skin of iron nitride which absorbs nitrogen from the dissociated ammonia and transmits it to the underlying α-iron, through which the nitrogen diffuses away in the direction of the core. Once the nitride layer has formed, the rate at which the case increases in depth is determined by the rate of diffusion of nitrogen in the α-iron, which is constant for any given temperature. From this it follows that if the composition of the nitriding atmosphere is such that a coating of nitride is formed on the surface of the steel, and remains there throughout the treatment, then the case depth produced in a given period of time, *after this layer has formed*, should be independent of the composition

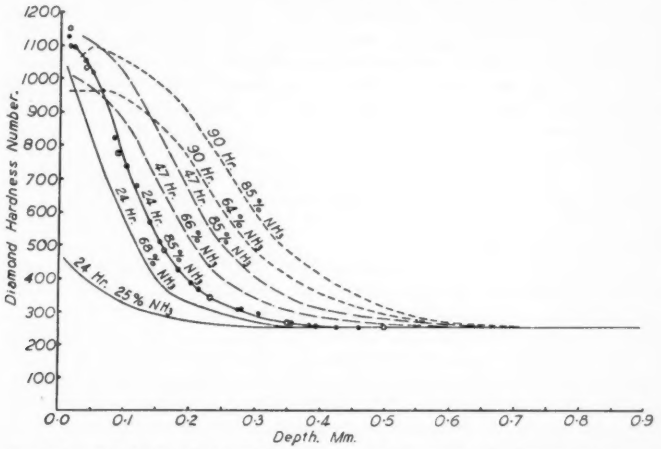


FIG. 18.—Steel *C*3, nitrided in ammonia and ammonia-hydrogen mixtures.

of the gas. Microscopic examination of all the specimens nitrided in ammonia mixed with hydrogen showed that while no visible nitride had been formed in the 25% ammonia-hydrogen mixture, those nitrided in the gas containing about 65% of ammonia were coated with a nitride layer which was about 0·02 mm. thinner than the corresponding layer formed in anhydrous ammonia. It appeared to the authors therefore that the decrease of about 0·04 mm. in the case depth, that was caused by diluting the ammonia with hydrogen, could be accounted for by assuming that an excess of hydrogen delays the formation of the nitride layer, and that the rate at which the nitrogen is absorbed by the steel does not reach its normal value until this stage has been completed. This conclusion was tested by nitriding a number of specimens of steel *C*3 for various periods,

ranging from several hours to a few minutes, in anhydrous ammonia, and then continuing the treatment till the total nitriding time was 24 hr. in each case, in a mixture of hydrogen and ammonia containing approximately 63% of the latter (measured in the waste gas). The purpose of the preliminary treatment in ammonia was to produce a nitride layer on the surface of the steel, and its duration was varied so as to find how long this layer took to form.

In the earlier experiments of this series, the procedure followed consisted in heating the steel in anhydrous ammonia for the required length of time, and then adding hydrogen to the gas stream, but owing to the relatively low velocity of the gas and the large volume of the furnace, it was some time before the gas in the furnace reached its final composition (63% ammonia). In the later experiments, when the preliminary treatment was brief, this difficulty was overcome by modifying the procedure in the following way. The specimens were placed in the nitriding furnace, which was then filled with ammonia and heated to 500° C. for the required time, and then cooled, with the gas still flowing—in the final experiment of the series the heating current was switched off as soon as the furnace reached 500° C., so that the effective nitriding time was only a few minutes. When the furnace had cooled to near room temperature, the composition of the gas was adjusted by adding hydrogen to it, and the furnace was reheated to 500° C. for the period required to bring the total time to 24 hr.

All these treatments hardened the steel to exactly the same extent as nitriding in pure ammonia. To illustrate this point the results obtained with preliminary treatments of (*a*) 1½ hr., (*b*) ½ hr., and (*c*) a few minutes, are shown in Fig. 18. All the hardness readings obtained in experiments (*a*) and (*b*) are marked in this graph as dots, while those for experiment (*c*) are recorded as small circles. As will be seen, all the points lie very close to the depth-hardness curve of the specimen nitrided for 24 hr. in ammonia. These experiments indicate that the nitride layer forms in a few minutes in anhydrous ammonia.

It was shown in an earlier section of the paper that a mixture of ammonia and nitrogen, containing only 16% of the former, nitrides steel as effectively as the pure gas, but that if the amount of nitrogen is further increased the hardness and depth of the case are reduced. These results, however, were obtained by using the mixed gas during the whole of the treatment. To find whether the incomplete hardening in the dilute mixtures was due to a delay in the formation of the nitride layer, 3 specimens of steel *C*5 were nitrided for half an hour in ammonia and then for 23½ hr. in a mixture of nitrogen and ammonia of such composition that the waste gas contained only 4% of the latter. After this treatment it was found that the specimen nearest to the gas inlet was hardened as fully as by anhydrous ammonia, but that the case of the specimen nearest to the outlet was softer and shallower. Microscopic examination

of the specimens revealed a nitride layer on the former, but not on the latter. This shows that a concentration of about 4% of ammonia in the nitriding atmosphere was not enough to maintain the nitride layer formed on the surface of the specimen by the preliminary treatment with ammonia. The concentration of ammonia in contact with the specimen nearest to the inlet (which was fully hardened) would of course be over 4%—but probably well under 10%. It is evident therefore that once the nitride layer has been formed on the outside of the specimen, which only requires a brief treatment in ammonia, the gas may be diluted with about 10 times its volume of nitrogen without affecting the efficiency of the process.

The Effect of the Condition of the Steel Surface.

As it has been found that a layer of iron nitride forms rapidly on the surface of the steel during nitriding in ammonia, and that thereafter the rate of nitriding is determined by the rate of diffusion of nitrogen in α-iron, it is not to be expected that the physical condition of the surface of the steel would have any appreciable effect on the efficiency of the process. This question was, however, investigated by nitriding a number of specimens of steel *C*5 for 24 hr. in ammonia after preparing them as follows: (*a*) by grinding on Hubert emery paper No. 1, (*b*) by grinding on No. 00 paper, (*c*) by grinding on No. 000 paper, (*d*) by polishing with magnesia on cloth, and (*e*) by polishing with magnesia and then etching deeply with 1% nitric acid in alcohol. These treatments had no effect on the process, as was shown by the fact that the depth-hardness curves for all the specimens coincided. The effect of a more drastic alteration of the surface was then examined. Specimens of steel *C*3 were heated successively in moist nitrogen (an oxidising agent) and in dry hydrogen (a reducing agent) for 7 periods of 40 min. each, finishing with a 60-min. treatment in hydrogen to ensure complete reduction of the surface of the metal; the temperature used was 500° C. The specimens were then nitrided in the usual way for 24 hr. This treatment had no measurable effect on the depth or hardness of the case, except that an unusually low hardness reading of 950 Vickers was obtained in the nitride layer, less than 0·02 mm. below the surface. The only deduction that can be drawn from this, however, is that the alternating oxidations and reductions had apparently made the nitride layer more brittle than usual.

The Effect of Rapid Cooling and Ageing.

Specimens of the two steels, *C*3 and *C*5, were nitrided for 47 hr. in ammonia, and quenched in cold water directly from the furnace, without turning off the heating current or the gas stream. On comparing the depth-hardness curves of the water-quenched specimens with those of the corresponding steel slowly cooled after

nitriding for the same period, it was found that the rapid cooling had no appreciable effect on steel *C*5. The upper part of the case of steel *C*3 (to a depth of less than 0·15 mm.) was softer by about 50 Vickers after water-quenching than after slow cooling, but the hardness of the rest of the case was quite unaltered. The depth-hardness curve of the quenched specimen of steel *C*5 was re-determined 42 days later, but no measurable change was detected.

The authors wish to express their indebtedness to Sir Harold Carpenter, F.R.S., in whose laboratories the work was carried out, for his helpful interest in the research.

REFERENCES.

(1) HOMERBERG and WALSTED: *Transactions of the American Society for Steel Treating*, 1929, vol. 16, Nitriding Symposium, p. 92.
(2) ROBERT SERGESON: *Transactions of the American Society for Steel Treating*, 1929, vol. 16, Nitriding Symposium, p. 156.
(3) GUNNAR HÄGG: *Proceedings of the Royal Swedish Institute for Engineering Research*, 1937, No. 143.
(4) "Gmelins Handbuch der anorganischen Chemie," Iron (A), pp. 1723–1725.
(5) MELLOR: "Handbook of Inorganic and Theoretical Chemistry," vol. 8, p. 156.

CORRESPONDENCE.

Mr. B. JONES (Cardiff) wrote that a more accurate title for the paper would be the " mechanism of nitride-hardening of chromium-aluminium steels," in view of the restriction to this type of steel. There were many other types of nitriding steels now available and being hardened on a routine production scale. While some of the features of the paper were of interest theoretically, it must be stated that most of the data given were well known and had been published before in detail. The investigations on the nitride-hardening of chromium-aluminium steels published in the Nitriding Symposium of the American Society for Steel Treating,[1] by Nishigori [2] and by Jones and Morgan,[3] had covered much of the ground attempted by the authors, although the two latter papers were not referred to.

It was now generally accepted from X-ray tests carried out in many countries that the great hardness obtained by nitriding a chromium-aluminium steel was due to the formation of alloy nitrides, complex in chemical composition and distorted in structure, which caused an extraordinary distortion of the α-iron crystal lattice. This lattice distortion was revealed by highly-diffused spectrum lines of α-iron in the X-ray diffraction pattern, as shown by Wood,[4] &c.

The nitride needles found in the marginal zone of the case were examined by Nishigori (*loc. cit.*), who concluded from his X-ray tests that they consisted of a ternary compound of iron, aluminium and nitrogen. It was unfortunate that the authors did not determine the nitrogen content of the steel after reheating in an atmosphere of hydrogen, as this would have given direct evidence that the remaining hardening was due to dispersed particles of alloy nitrides or to nitride particles which included iron nitride. If, however, all the iron were found to be uncombined with nitrogen and a diamond hardness of 850 remained, then the composition of the nitrides which caused this hardening might be found.

One of the objects of the investigation was " to find whether the process could be speeded up by modifying the nitriding conditions," but the annealing treatments, &c., described did not indicate progress in this direction. The writer considered that the two-stage method of nitriding investigated by him [5] was the only

[1] *Transactions of the American Society for Steel Treating*, 1929, vol. 16, Nitriding Symposium.

[2] S. Nishigori, *Technology Reports of the Tôhoku Imperial University*, 1935, vol. 11, p. 623.

[3] B. Jones and H. E. Morgan, *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1932, vol. 21, p. 39.

[4] W. A. Wood, *Philosophical Magazine*, 1933, vol. 16, p. 719.

[5] B. Jones, *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1934, vol. 23, p. 139.

satisfactory method to hasten the depth-hardening in the chromium-aluminium type of Nitralloy steel.

AUTHORS' REPLY.

The AUTHORS wrote thanking Mr. Jones for his interesting contribution. They were familiar with his papers in the *Carnegie Scholarship Memoirs*, but so many papers on nitriding had been published (there were several hundred references to the literature on the subject in Gmelins "Handbuch") that it was impossible to refer to them all, or even to all the important ones, without adding considerably to the length of the paper. They had adopted the plan of outlining the accepted views concerning the mechanism of the process, which were based on the papers mentioned by Mr. Jones and on many others, and had restricted their references to a few papers dealing with points with which they were particularly concerned.

They believed that if Mr. Jones were to re-read their paper, he would find that he was mistaken in thinking that most of the data in it had been published before in detail. They themselves had carefully re-examined the papers mentioned by Mr. Jones, and had not found in them any detailed data on the effect of annealing nitrided steels in nitrogen and hydrogen, or of adding various proportions of these gases to the nitriding atmosphere, or of treating the surface of the steel in various ways before nitriding. The paper by Nishigori contained much useful information, but mainly about matters other than those with which the authors' paper dealt. Nishigori surmised that the new phase which he detected in nitrided Nitralloy steel might be a ternary compound, possibly a nitride of iron with aluminium or chromium, but he did not determine its composition or crystal structure. This constituent was found by X-ray examination of the *surface* of the steel, and it was by no means proved that the needles in the case were composed of this phase—or that the phase was a ternary nitride. The most recent X-ray work on nitrided Nitralloy steel was that of Hägg (reference (3) in the paper), who investigated the structure from the surface inwards, and found that the needles were composed of iron nitride (γ').

The authors were indebted to Mr. Jones for the suggestion that a determination of the nitrogen content of nitrided specimens annealed in hydrogen might yield useful information as to the composition of the nitrides responsible for the dispersion hardening. They had, of course, no expectation of increasing the rate of nitriding by annealing the nitrided specimens. As they had stated in the last sentence of the Introduction, it was "particularly by some preliminary treatment of the surface of the steel" that

they had hoped originally that some increase might be achieved. This idea was suggested to them by the fact that the diffusion of certain gases through some metals was greatly affected by the condition of the surface; the rate of diffusion of hydrogen through iron, for example, was increased ten times by etching the surface of the metal with dilute nitric acid.[1] It was found, however, that the surface treatments had no measurable effect on the rate of nitriding, probably because in this process the surface of the metal rapidly became coated with a skin of iron nitride—once this had formed, it was the underside of the nitride layer, and not the surface of the specimen, that supplied the nitrogen to the underlying steel.

[1] Smithells and Ransley, *Proceedings of the Royal Society*, 1935, vol. 150, p. 172.

FURTHER EXPERIMENTS ON THE NITROGEN-HARDENING OF HIGH-CHROMIUM AND AUSTENITIC STEELS.*

By B. JONES, M.Sc., F.I.C. (University College, Cardiff).

(Figs. 3 to 20 = Plates XIII. to XVII.)

Synopsis.

The nitrogen-hardening properties of high-chromium and austenitic steels have been examined after treatment of the surfaces by copper-plating and with phosphate reagent. Regular hardening by these methods was obtained. The greatest hardening was produced by nitriding within the range 500–550° C.; a temperature of 600–610° C. is suitable for only the more highly-alloyed materials, such as the heat-resisting steels. Nitriding at a temperature greater than 600–610° C. results in decreased hardness values for all steels, and the increase in case depth is negligible for austenitic steels. X-ray crystal analysis and a microscopical examination were carried out on some of the nitrided steels. X-ray diffraction spectra were obtained from the surface and at various depths within the nitrided case to determine its chemical constitution after nitriding at 550° C. The surfaces of the ingot iron, 8% nickel steel, and 13% chromium steel show the presence of the ϵ-phase of the iron-nitrogen system, indicating a nitrogen content of approximately 8–11%. This phase is not revealed in the austenitic steels. The surface layer of the 18/8 chromium-nickel steel consists of the γ' Fe_4N phase, together with chromium nitride, CrN. No evidence was obtained for the formation of a nitride of nickel in any of the steels examined, but, in the austenitic steels, nickel is probably dissolved in the nitrides formed, by a replacement of the metal atoms. The 14/14/2 chromium-nickel-tungsten steel gives lines at the surface which indicate the presence of the γ' nitride phase, corresponding to the composition $(FeCrNi)_4N$. While the spectrum lines obtained from the nitrided ingot iron are well defined and show no distortion, those found in the nitrided high-chromium and austenitic steels are highly diffused. In the steels examined, tests indicate that both the alloy nitride and the crystal lattice of the steel itself are highly distorted, the distortion being so marked as to prevent the formation of a normal spectrum. A change of constitution has occurred in the nitrided 18/8 chromium-nickel steel, as shown by the presence of α-iron lines in the nitrided zone, the atomic lattice being, however, very distorted. The presence of α-iron was not detected in the more stable austenitic alloy, the 14/14/2 chromium-nickel-tungsten steel, but the γ-iron lattice was very distorted, as shown by the very diffused spectrum lines in the zone of greatest hardness.

Introduction.

Recent developments in the nitriding process for case-hardening steels have been on the lines of extending the process to steels of

* Received July 9, 1937.

various compositions other than the chromium-aluminium type of steel discovered by Fry.[3] The author has investigated the nitriding properties of commercial steels of many types [1, 2] and has reported on the characteristics of the steels after subjecting them to the process at different temperatures and under various conditions. While there is no difficulty in the hardening of low-alloy steels containing a sufficient quantity of elements which form stable nitrides, the nitriding of certain high-alloy steels, such as the chromium and austenitic chromium-nickel steels, requires a preliminary treatment of the surfaces, owing to the presence of the oxide film.[13] The latter is sufficiently stable to prevent the dissociation of ammonia gas by catalysis, and prevents the diffusion of atomic nitrogen into the surface layers. When the oxide film is removed, *e.g.*, by treatment of the steels with hydrochloric acid, &c., as described by Hatfield and Green,[5] by sprinkling with halogen compounds,[7] by treatment with phosphate reagent,[8] or by coating the steels with a metal or metalloid as proposed by Sutton, Sidery and Evans,[6] the steels will then absorb nitrogen, and will harden to an extent depending upon their chemical composition. Tests have shown [2, 6] that it is an advantage in the treatment of austenitic steels to raise the nitriding temperature above the usual one of 460–500° C. employed for low-alloy steels, owing to the greater difficulty of nitrogen penetration into the highly alloyed steels. While satisfactory results have been obtained [2] by the hydrochloric-acid method of treatment prior to nitriding, probably the most widely used method in Britain is that of copper-plating the surfaces by electrodeposition, after a preliminary pickling of the steels in sulphuric acid.[6] The chief application of the latter method is for the nitriding of austenitic chromium-nickel-tungsten heat-resisting steels, a process which is now a routine production operation for the hardening of the stems of aero-engine valves, &c. The treatment overcomes the former difficulties which arose from the low Brinell hardness of the steels. The advantages obtained by nitriding are the reduction of excessive wear of the stem and valve guide,[14] thus increasing appreciably their service life, while, in addition, the bearing properties of the valve in contact with the guide are improved. The above method of nitriding is also used for hardening the surface of liners for aero-engine cylinders, when these are made of austenitic steel. In view of the commercial interest of certain nitrided austenitic steels, the author has carried out these further experiments dealing with the copper-plating method and the more recently developed phosphate method,[8] for the treatment of various steels before nitriding. The hydrochloric-acid method has already been tested.[2]

The nitriding of the steels was carried out for 90 hr. in the experimental furnace already described [2]; the rate of supply of the ammonia gas was controlled by a dissociation pipette, and the temperature was kept under automatic control. The gas was

passed under a pressure of approximately 1 in. water-gauge, as in commercial practice. The temperatures investigated were 500–510° C., 550–560° C., 600–610° C. and 650–660° C. The specimens were mostly in the form of cylinders approximately $\frac{3}{4}$ in. in dia. and $\frac{1}{2}$ in. long. These were weighed and measured before and after nitriding, these data giving approximately the amount of nitrogen absorbed. The chemical compositions of the steels examined are given in Table I. It should be noted that while the nitrided steels, other than the austenitic heat-resisting steels, have, as yet, no practical application, their nitriding characteristics are useful, because the effects of both chromium and nickel can be studied. Little is known of the chemical composition of the nitrided layer in these complex steels, because microscopical tests do not give sufficient information. X-ray tests on certain of the steels have, therefore, been included.

TABLE I.—*Chemical Analysis.*

No.	C. %.	Si. %.	Mn. %.	Cr. %.	Ni. %.	W. %.	Al. %.	Heat Treatment.
1	0·28	0·18	0·25	13·40	0·35	...	...	O.Q. 950° C., T. 600° C.
2	0·16	0·10	0·54	17·20	1·40	...	...	A.H. 975° C., T. 600° C.
3	0·26	0·95	0·55	26·30	0·25	...	...	...
4	0·13	0·32	0·17	18·14	8·75	...	...	W.Q. 1050° C.
5	0·15	0·48	0·13	18·15	7·98	...	1·01	W.Q. 1050° C.
6	0·09	1·98	0·70	22·70	9·10	...	...	A.C. 1050° C.
7	0·12	0·13	0·69	14·80	10·80	...	...	W.Q. 1050° C.
8	0·14	0·07	0·60	12·10	11·80	...	...	A.C. 1050° C.
9	0·14	0·71	0·22	25·84	13·06	...	...	A.C. 1050° C.
10	0·40	0·89	0·65	13·00	12·80	2·20	...	A.C. 950° C.
11	0·47	1·38	1·39	13·40	26·50	3·54	...	W.Q. 1000° C.

TREATMENT OF THE STEELS PRIOR TO NITRIDING.

The polished steels were cleaned in rectified spirits and given the following treatments:

(a) *Copper-Plating Method.*—The steels were immersed in hot 10% sulphuric acid for a sufficient time to etch the surface lightly; they were then rinsed in water and transferred to a copper cyanide plating bath.

A coating of 0·00001–0·000015 in. (0·00025–0·00037 mm.) of copper was deposited. The time of plating was carefully determined beforehand.

(b) *Phosphate Method.*—The bath consisted of cadmium phosphate reagent, which was prepared as follows: Eighty grammes of cadmium in the form of strip were dissolved in hydrochloric acid, and the excess acid was evaporated to incipient crystallisation; 200 ml. of orthophosphoric acid were added to produce a large

TABLE II.—*Nitriding of High-Chromium and Austenitic Steels at Various Temperatures.*

Steel.	No.	Surface Treatment prior to Nitriding.‡	Temperature of Nitriding and Dissociation. Time, 90 hr.													
			500–510° C., 20–25%.				550–560° C., 25–35%.				600–610° C., 35–45%.				650–660° C., 45–55%.			
			Diamond Hardness of Surface.	Max. Hardness under Surface.	Depth of Case. In.	Depth of Case. Mm.	Diamond Hardness of Surface.	Max. Hardness under Surface.	Depth of Case. In.	Depth of Case. Mm.	Diamond Hardness of Surface.	Max. Hardness under Surface.	Depth of Case. In.	Depth of Case. Mm.	Diamond Hardness of Surface.	Max. Hardness under Surface.	Depth of Case. In.	Depth of Case. Mm.
C 0·28%, Cr 13·40%.	1	*C*	725, 850	1050	0·012	0·30	670, 710	1020	0·015	0·38	730, 730	780	0·018	0·46	510, 520	600	0·024	0·60
		P	780, 820	1100	0·012	0·30	680, 750	1030	0·015	0·38	720, 735	770	0·019	0·48	520, 550	610	0·026	0·66
C 0·16%, Cr 17·20%, Ni 1·40%.	2	*C*	1050, 1180	1220	0·008	0·20	880, 950	1150	0·013	0·33	850, 890	950	0·016	0·40	650, 725	At surface	0·020	0·51
		P	1000, 1080	1220	0·009	0·23	800, 880	1150	0·013	0·33	810, 910	940	0·016	0·40	700, 730	At surface	0·021	0·53
C 0·26%, Cr 26·30%.	3	*C*	320, 760	1000	Irregular		950, 1050	1200	0·0075	0·19	1050, 1100	1200	0·009	0·23	500, 630	670	0·017	0·43
		P	... *	1200	0·006	0·15	... *	1200	0·009	0·23	... *	1180	0·010	0·25	... *	700	0·018	0·46
C 0·13%, Cr 18·14%, Ni 8·75%.	4	*C*	850, 1000	1220	0·008	0·20	900, 950	1100	0·0105	0·27	620, 830	950	0·012	0·30	400, 480	700	0·012	0·30
		P	900, 980	1220	0·009	0·23	760, 850	1020	0·010	0·25	720, 750	1000	0·012	0·30	470, 490	680	0·012	0·30
C 0·15%, Cr 18·15%, Ni 7·98%, Al 1·01%.	5	*C*	950 † approx.	1220	0·008	0·20	900, 920	1120	0·011	0·28	800, 850	1200	0·013	0·33	500, 570	920	0·014	0·35
		P	... *	1050	0·009	0·23	... *	1150	0·012	0·30	780, 880	1200	0·014	0·35	580, 600	950	0·014	0·35
C 0·09%, Si 1·98%, Cr 22·70%, Ni 9·1%.	6	*C*	750, 900	1150	0·006	0·15	900, 1000	1050	0·008	0·20	700, 820	1050	0·009	0·23	620, 640	850	0·010	0·25
		P	740, 920	1000	0·006	0·15	990, 1000	1200	0·0085	0·21	820, 830	1100	0·0095	0·24	580, 630	870	0·010	0·25
C 0·12%, Cr 14·80%, Ni 10·8%.	7	*C*	950, 980	1070	0·007	0·18	960, 1020	1050	0·010	0·25	700, 730	850	0·012	0·30	480, 500	640	0·012	0·30
		P	... *	1220	0·008	0·20	... *	1080	0·010	0·25	730, 800	820	0·012	0·30	550, 570	650	0·013	0·33
C 0·14%, Cr 12·10%, Ni 11·80%.	8	*C*	760, 890	1050	0·003	0·08	1000, 1020	1020	0·008	0·20	730, 820	900	0·009	0·23	460, 480	610	0·0095	0·24
		P	... *	1100	0·0035	0·09	990, 1020	1000	0·008	0·20	730, 850	890	0·009	0·23	450, 480	600	0·0095	0·24
C 0·14%, Cr 25·84%, Ni 13·06%.	9	*C*	250, 450	480	Irregular		1050, 1100	1100	0·0045	0·11	920, 960	1080	0·005	0·13	580, 590	700	0·0055	0·14
		P	390, 480	490	Irregular		1000, 1050	1080	0·0045	0·11	900, 950	1050	0·005	0·13	530, 550	720	0·005	0·13
C 0·40%, Si 0·89%, Cr 13·00%, Ni 12·80%, W 2·20%.	10	*C*	810, 960	1000	Irregular		950, 970	1050	0·006	0·15	950, 990	1100	0·007	0·18	620, 620	780	0·009	0·23
		P	750, 980	1020	0·0035 approx.	0·09	980, 960	1100	0·0065	0·16	950, 970	1080	0·007	0·18	600, 620	700	0·009	0·23
C 0·47%, Si 1·38%, Mn 1·39%, Cr 13·40%, Ni 26·5%, W 3·54%.	11	*C*	510, 570	580	Irregular		780, 850	940	0·003 approx.	0·08	780, 880	930	0·0045	0·11	680, 740	750	0·0055	0·14
		P	580, 620	660	0·002 approx.	0·05	890, 950	980	0·003 approx.	0·08	860, 950	990	0·0045	0·11	600, 660	720	0·0055	0·14
Nichrome: Ni 65%, Cr 15%, Fe 20% approx.	...	*C*	220	...	...		280	...	...		250	...	...		245	...	...	
		P	210	...	...		260	...	...		245	...	...		245	...	...	

* Rough surface due to overpickling in phosphate reagent. † Spalled surface. ‡ *C* = Copper-plated. *P* = Phosphate.

precipitate of cadmium orthophosphate, and the volume was adjusted to 600 ml. by the addition of water. The precipitate dissolved on boiling. The steel specimens were immersed in the boiling solution for a length of time which varied according to their chemical composition. The time found suitable for the chromium-nickel-tungsten and the 18/8 chromium-nickel austenitic steels was 30 min., while other austenitic steels required less time, owing to an increased rate of attack. The plain chromium steels were all rapidly attacked, and a few minutes' immersion was sufficient. The steels were afterwards rinsed in hot water and dried. They possessed a light grey matte surface after treatment.

Results of Experiments.

The results are summarised in Table II.

The copper-plated steels after nitriding still showed the presence of the copper deposit on parts of the surface, which was, however, practically covered with a dull grey film. This indicates that copper does not form a nitride, and remains unaffected by the nitriding process. The steels previously treated with phosphate reagent were of a dull grey character after nitriding. The growth in all steels nitrided at 600–610° C. and below was less than 0·002 in. The chromium steels underwent the greatest growth, owing to the increased quantity of nitrogen absorbed, while the least volume change was shown by the austenitic heat-resisting steels (approximately 0·0005 in.). The growth was much less than that found in low-chromium steels.[2] After nitriding at 650–660° C., however, the surfaces of the steels were slightly distorted, with the exception of the heat-resisting austenitic steels.

The hardness of the surface was determined, after lightly polishing, by applying a load of 5 kg. on the diamond indentor, while the depth of case reported was obtained from depth-hardness measurements. In all the steels the degree of hardness obtained was comparable with that found in the low-alloy Nitralloy steels, but the depth of case was smaller.

There is a marked restraining action to the diffusion of nitrogen in these high-alloy steels; both the copper-plating and the phosphate methods give appreciably the same results. It was found, however, that when some of the steels were over-pickled in the phosphate reagent, the surfaces remained rough after nitriding, but the depth of hardening was increased. The depth of case produced in the plain chromium steels (Nos. 1–3) is reduced as the chromium content of the steel increases, although it is greater than that found in austenitic steels containing the same amount of chromium. The results obtained on steels Nos. 1, 7, 10 and 11 indicate that a progressively thinner case is obtained when an increasing amount of nickel is incorporated in the composition. Increasing the nickel to an appreciable extent destroys the hardening capacity, as shown

‡ C = Copper-plated. P = Phosphate.
† Spalled surface.
• Rough surface due to overpickling in phosphate reagent.

by the sample of Nichrome (Table II.). There is evidently great difficulty for the penetration of nitrogen through austenite of a stable character, while nickel also restrains the hardening effect,

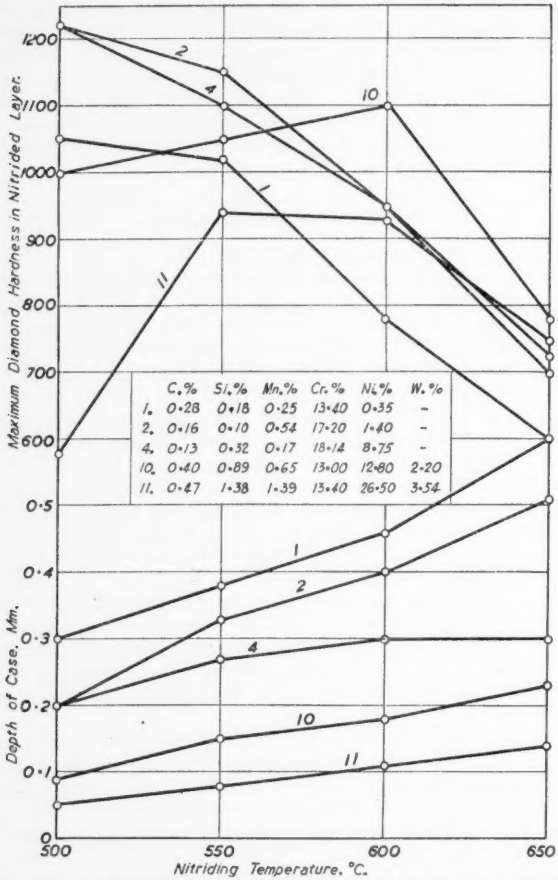


FIG. 1.—Effect of Nitriding Temperature on Depth of Case and Maximum Hardness of Steels (Copper-Plated).

because it does not combine with nitrogen to form a crystalline nitride, as will be shown later. While the greatest hardening effect is obtained in many of the steels by nitriding them at 500–510° C., irregular results occur in the more highly alloyed steels, and

especially those with a nickel content greater than approximately 12%. Better results are often obtained at this temperature by nitriding for a short time, cooling, and re-nitriding.[2] More uniform hardening occurs by increasing the temperature to 550–560° C.,

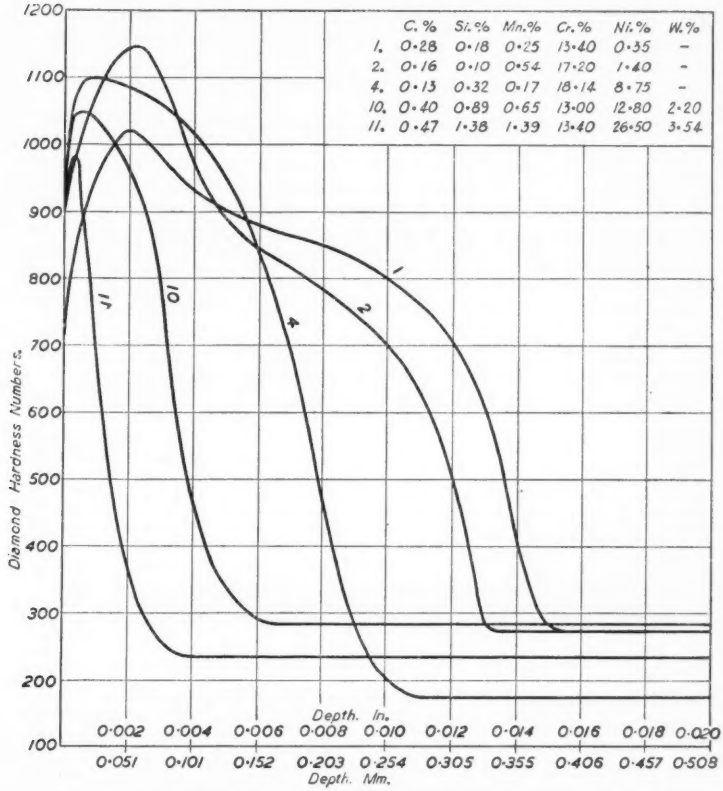


FIG. 2.—Depth-Hardness of Copper-Plated Steels Nitrided at 550–560° C. for 90 hr.

which also results in a greater depth-hardening in all steels. The nitriding of the heat-resisting steels Nos. 3, 9, 10 and 11 at 600–610° C. results in appreciably the same hardening effect as that obtained at 550–560° C., while the depth of case is slightly increased. A definite decrease in hardness, however, was found in the chromium and austenitic steels other than the above by nitriding at 600–610° C.

A temperature of 650–660° C. gave unsatisfactory results for all the steels, while the increased depth of case was found to be negligible in the austenitic steels. These features are shown in Fig. 1. Typical depth-hardness curves illustrating the effect of chromium and of chromium plus nickel after nitriding at 550–560° C. are given in Fig. 2. The decreased depth-hardening produced by the austenitic structure and by the increased nickel content of the steels is clearly shown.

Increase in Weight due to Nitriding.

Tests have indicated that the gain in weight by nitriding is due chiefly to the amount of absorbed nitrogen. As an example, the weight increase found by nitriding Nitralloy steel is appreciably greater than that obtained by nitriding austenitic steels, the hardness penetration being also greater; also, the nitrogen content of nitrided filings of various steels agreed appreciably with the increase in weight. The increase in weight of the steels after nitriding is calculated as the amount of nitrogen absorbed per unit surface area of 100 sq. cm. (*see* Table III.). A comparison of these

Table III.—*Calculated Weight of Nitrogen Absorbed.*

Gramme per 100 sq. cm. of surface area.

Steel.	No.	Nitriding Temperature.			
		500–510° C.	550–560° C.	600–610° C.	650–660° C.
C 0·28%, Cr 13·40%, Ni 0·35%	1	0·90	1·15	1·25	2·30
C 0·16%, Cr 17·20%, Ni 1·40%	2	0·65	1·00	1·10	1·65
C 0·13%, Cr 18·14%, Ni 8·75%	4	0·64	0·97	1·04	1·06
C 0·40%, Cr 13·00%, Ni 12·80%, W 2·20% . .	10	0·42	0·57	0·60	0·70
C 0·47%, Cr 13·40%, Ni 26·50%, W 3·54% . .	11	0·21	0·25	0·29	0·46
Nichrome (Ni 65%, Cr 15%, Fe 20%)	...	0·02	0·04	0·05	0·08

results with Figs. 1 and 2 shows that the chromium steels, which absorb the greatest amount of nitrogen, give the greatest depth of case, while the least amount is found in the high-nickel austenitic steels, in which there is only a narrow zone of hardening. Only a negligible amount of nitrogen is absorbed by Nichrome.

X-Ray Tests.

The X-ray tests were carried out at the author's request by the Physics Department of the National Physical Laboratory. As this is the first investigation, as far as the author is aware, into the constitution of these high-alloy steels after subjecting them to the nitriding process, it was felt that a comparison of the constitution of unalloyed iron, nitrided under similar conditions, should also be included. In addition, the nitrided surface of an 8% nickel steel

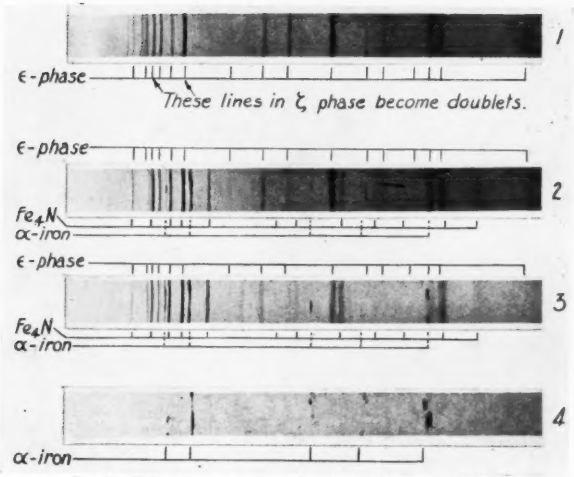


FIG. 3.—X-Ray Spectra of Ingot Iron Nitrided at 550–560° C.

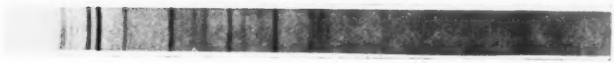


FIG. 4.—X-Ray Spectrum of 8·6% Nickel Steel Nitrided at 550–560° C.

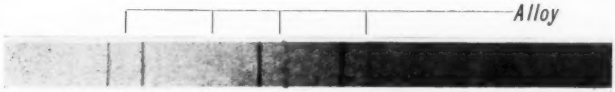


FIG. 5.—X-Ray Spectrum of 36% Nickel-Alloy (Invar) Filings Nitrided at 550–560° C.

[*Jones.*
[*To face p.* 176 P.

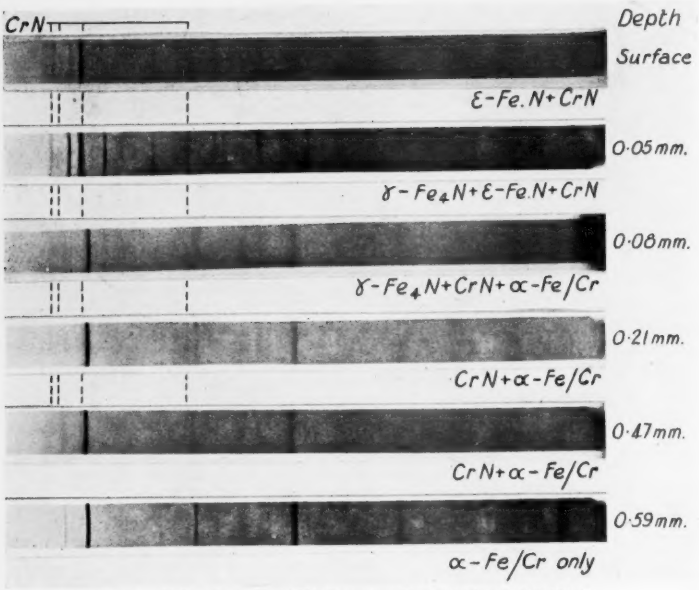


FIG. 6.—X-Ray Spectra of 13% Chromium Steel Nitrided at 550–560° C.

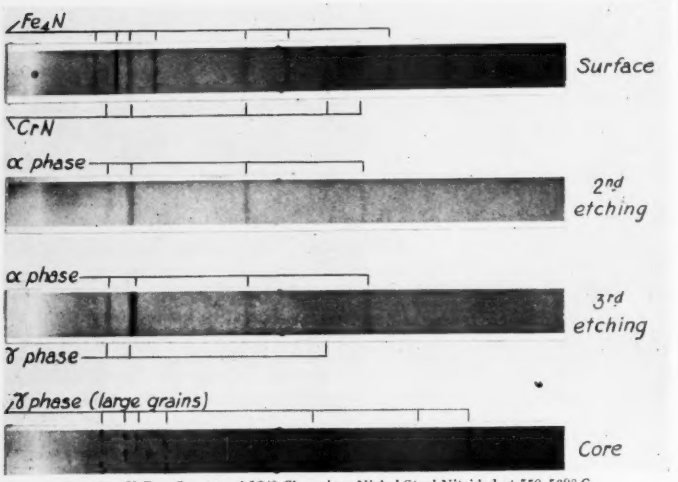


FIG. 7.—X-Ray Spectra of 18/8 Chromium-Nickel Steel Nitrided at 550–560° C.

[*Jones.*

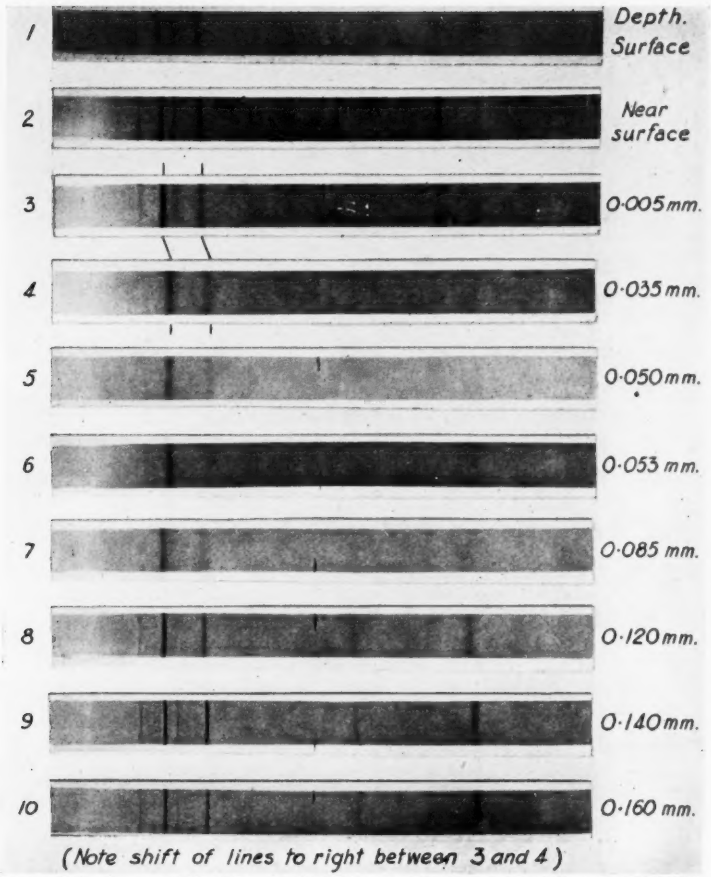


FIG. 8.—X-Ray Spectra of *KE*965 Chromium-Nickel-Tungsten Heat-Resisting Steel Nitrided at 550–560° C.

[*Jones.*

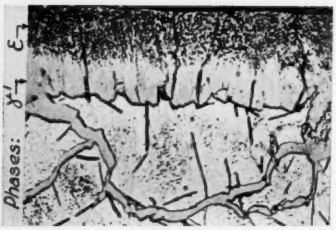


FIG. 9.—Ingot Iron Nitrided at 550–560° C. ε and γ′ compounds of iron nitride. × 350.

FIG. 10.—Zone near Surface of Fig. 9. × 350.

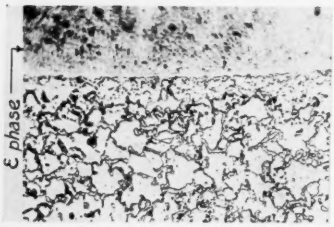


FIG. 11.—8·6% Nickel Steel Nitrided at 550–560°C. × 350.

FIG. 12.—Steel No. 1 (13·4% Chromium) Nitrided at 550–560° C. × 100.

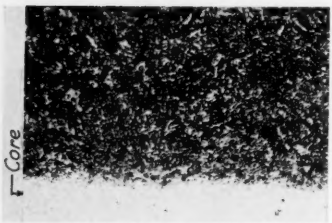


FIG. 13.—Structure near Core of Fig. 12. × 350.

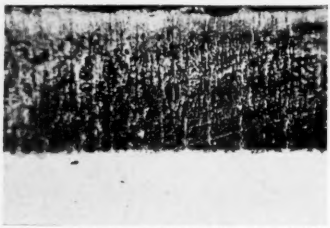


FIG. 14.—Steel No. 2 (17·2% Chromium, 1·4% Nickel) Nitrided at 550–560° C. × 100.

All steels etched in 4% alcoholic nitric acid.
(Micrographs reduced to two-thirds linear in reproduction.)

[*Jones.*

FIG. 15.—18/8 Chromium-Nickel Steel Nitrided at 550–560° C. × 100.

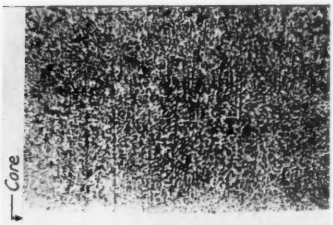


FIG. 16.—Structure near Core of Fig. 15. × 350.

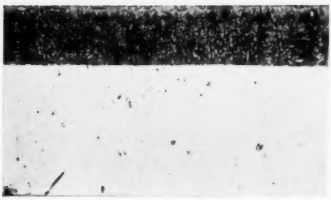


FIG. 17.—Steel No. 10 (*KE*965) Nitrided at 550–560° C. × 100.

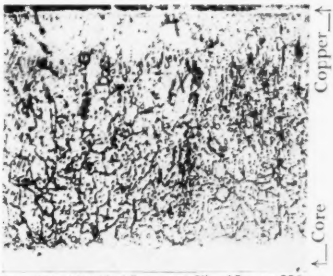


FIG. 18.—Nitrided Layer of Fig. 17. × 350.

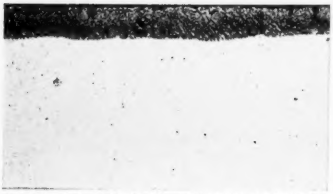


FIG. 19.—Steel No. 11 (Era *ATV*) Nitrided at 550–560° C. × 100.

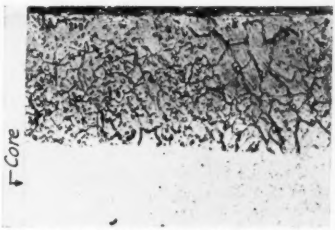


FIG. 20.—Nitrided Layer of Fig. 19. × 350.

All steels etched in 4% alcoholic nitric acid.
(Micrographs reduced to two-thirds linear in reproduction.)

[*Jones.*

has been examined, and some tests have been carried out on the constitution of nitrided filings. The technique used in securing the X-ray spectra was that of the "powder method." The steel was exposed to a beam of X-rays, approximately 1 sq. mm. in cross-section, proceeding in a direction perpendicular to the axis of the camera, and the spectra formed by the diffraction were recorded on a strip of photographic film wrapped round the circumference of the camera. The radiation used was the *K* wavelength of iron or cobalt. The angular inclination of the surface to the X-ray beam was adjusted to bring into focus the spectral lines deviating through angles of up to about 120° on the photographic film. The chemical composition of the surface layers was obtained by comparing the X-ray diffraction spectra with those of the compounds likely to be present, namely, nitrides of iron, chromium and nickel. The composition within the nitrided layer was similarly obtained by securing X-ray photographs from the specimens as the nitrided layer was dissolved away by means of *aqua regia* in measured stages; any loose residue was removed before each examination. Measurements of the overall thickness of the specimen at each stage with a micrometer gauge gave the amounts thus removed and the depth of penetration into the layer. A similarity between the observed and known spectra was taken to indicate the presence of the corresponding compound or phase. In this way an indication was obtained of the variation in composition occurring as the nitrided skin was penetrated. Owing to the high degree of absorption of the X-radiation by the specimen, the spectra indicate the state of the material in the immediate locality of the point from which they were obtained.

Results of X-Ray Tests.

(1) *Ingot Iron Nitrided at* 550–560° *C.*—The X-ray spectra are illustrated in Fig. 3. The surface consists of the hexagonal ε phase of the iron-nitrogen system. The estimated size of the hexagonal unit cell is

Side of base, $a = 2{\cdot}73$ Å.
Height of cell, $c = 4{\cdot}39$ Å.

The dimensions of the unit cell are known to vary with the nitrogen content. The above dimensions would correspond to a nitrogen content of 9·5% on the assumption that the size of the cell increases uniformly in the range 8–11% nitrogen.[9] The ζ or orthorhombic phase, corresponding to the compound Fe_2N, was not found; the latter gives a spectrum which is very similar to that of the ε phase but differs in that certain lines assume a doublet formation. This point is illustrated in the first photograph. Nos. 2 and 3 show the composition at a distance of 0·003 cm. and at 0·005 cm. respectively, this being a mixture of the above ε phase, the γ′ or Fe_4N phase, and α-iron. They differ only in the relative proportions of the constituents. The dimensions of the unit cells of the ε phase appear to be slightly less than in the same phase on the original

surface, indicating some diminution of nitrogen content. The edge of the Fe_4N phase, face-centred cubic, which is stated to form at a nitrogen content of 5·9% or less, was found to be $a = 3·79$ Å. No. 4 shows that the lines due to the nitrides are only very faint at the depth examined (approximately 0·008 cm.), while the spectral lines of the α-iron are spotted, indicating the large grain size (approximately 10^{-2} cm.). The edge of the unit cell of the α-iron corresponds with the normal value of 2·86 Å.

(2) 8% *Nickel Steel* (*Carbon* 0·10%, *Nickel* 8·6%) *Nitrided at* 550–560° *C.*—The spectrum given by the surface of this specimen is reproduced in Fig. 4. It is resolved into two constituents, (*a*) that arising from the ε phase, definitely similar to that found in ingot iron, and (*b*) lines due to a small proportion present of the γ′ or Fe_4N phase.

(3) *Filings of Invar* (*Carbon* < 0·02%, *Nickel* 35·8%) *Nitrided at* 550–560° *C.*—The object of this test was to examine the composition of the nitrides formed in a high-nickel alloy when the nitriding was as complete as possible, the possible formation of nitrides of nickel being especially looked for. The nitrided powder was mounted on the surface of a glass strip with Canada balsam, and the X-ray test was carried out as before. The spectrum is shown in Fig. 5, and was a composite one, which was resolved into the two separate spectra of (*a*) the γ′ phase, Fe_4N, and (*b*) a γ or face-centred cubic alloy of the Ni–Fe system. The two phases accounted for all the lines observed; *there was no sign, in particular, of any nitride of nickel.* The lines of the γ′ phase were specially strong and sharp, and preponderated; in comparison, the spectrum of the Ni–Fe alloy was reasonably sharp but distinctly weaker. The γ′ phase is cubic, the side of the cell being $a = 3·79$ Å, and approximates to the formula Fe_4N. The structure of the Ni–Fe alloy resembles that of nickel, both possessing a face-centred cubic cell. The size of cell observed for the alloy was 3·6 Å; the latter differed from that of pure nickel, for which $a = 3·517$ Å, and indicates that the alloy found after nitriding still contains in solid solution an appreciable amount of iron.

(4) 13% *Chromium Steel No.* 1 (*Carbon* 0·28%, *Chromium* 13·4%, *Nickel* 0·35%) *Nitrided at* 550–560° *C.*—This steel was examined at the surface and at various depths below the surface; the chemical composition of the nitrided layers found is summarised below :

Depth below Surface.	Chemical Compound shown in X-ray Spectrum.			
Surface.	ε-Fe–N	CrN (weak)	...	...
0·01 mm.	ε-Fe–N	CrN (weak)	...	...
0·05 mm.	ε-Fe–N (trace)	CrN (weak)	Fe_4N (strong)	...
0·08 mm.	...	CrN (weak)	Fe_4N (weak)	Fe–Cr (strong)
0·21 mm.	...	CrN (weak)	...	Fe–Cr (strong)
0·27 mm.	...	CrN (weak)	...	Fe–Cr (strong)
0·32 mm.	...	CrN (weak)	...	Fe–Cr (strong)
0·39 mm.	...	CrN (weak)	...	Fe–Cr (strong)
0·47 mm.	...	CrN (weak)	...	Fe–Cr (strong)
0·59 mm.	...	...	...	Fe–Cr (strong)

Representative X-ray photographs are reproduced in Fig. 6. The surface consists mainly of the ε phase of iron nitride, which is known to form at a nitrogen content of 8–11%. The structure is hexagonal, with a unit cell of size :

Side of base, $a = 2{\cdot}72$ Å.
Height of cell, $c = 4{\cdot}40$ Å.

In addition, evidence is found of CrN, which is cubic in structure with a side of cell 4·14 Å. At a depth of 0·05 mm. the ε phase decreases in quantity and is replaced by the γ' phase, which corresponds to a lower nitrogen content, equivalent to Fe_4N. This material is cubic, the side of the cell being 3·79 Å; a trace of CrN remains. The α phase of the Fe–Cr alloy appears at a depth of 0·08 mm., where the γ' phase diminishes in quantity. At a depth of 0·21 mm. the γ' phase has disappeared, only the alloy and the CrN lines remaining. This state is maintained at a depth of 0·47 mm., and the last trace of CrN is in the spectrum at this depth. The structure of the skin changes not only in chemical composition but also most strikingly in degree of perfection. Each compound, including the alloy itself, down to a depth of 0·47 mm., is highly distorted; the distortion is so marked as to prevent the formation of a normal spectrum, the higher orders becoming so diffuse as to disappear entirely. The effect is shown, in the photographs reproduced, by the right-hand half, which should contain a number of lines but which actually is practically clear. When the nitrided layer is penetrated, at a depth of 0·59 mm., the spectrum of the alloy is restored and becomes sharp throughout the range in the normal way. The side of cube of the Fe–Cr alloy = 2·86 Å.

(5) 18/8 *Chromium-Nickel Steel No.* 4 (*Carbon* 0·13%, *Chromium* 18·14%, *Nickel* 8·75%) *Nitrided at* 550–560° *C.*—X-ray spectra were obtained from the surface and within the nitrided layer (Fig. 7). The surface layer consists of the γ' Fe_4N phase, which is face-centred cubic with a side of cube 3·79 Å, together with CrN, with a side of cube 4·14 Å, the nitride of iron preponderating. There is no evidence of a nitride of nickel in crystalline form, although either of the above phases may contain a proportion of nickel in solid solution without measurable change in size of the elementary cube. After a first etching, the nitrided layer near the surface consisted of the above two nitrides, together with a trace of the α body-centred phase of iron. A second etching showed the layer to consist mainly of the α phase of iron, together with a little CrN. The side of the elementary cube of α-iron, deduced from the position of the lines, was 2·88 Å; this value is larger than the value 2·86 Å for normal iron, which indicates that the α phase contains nickel in solid solution in the iron lattice. The lines of the spectrum of the α phase were diffuse, indicating that the crystallites were submicroscopic in size and probably distorted in structure. After a third etching, which did not remove more than 0·10 mm. (0·004 in.), the nitrided layer still contained a preponderance of the α phase, but also traces of the γ

structure. A further deep etching removed the α phase and left only the γ phase, similar to the condition of the original specimen, and indicated that the nitrided skin had been completely removed. The side of the cube of the γ phase is approximately 3·63 Å.

(6) KE965 *Heat-Resisting Steel No.* 10 (*Carbon* 0·40%, *Silicon* 0·89%, *Chromium* 13·0%, *Nickel* 12·8%, *Tungsten* 2·2%) *Nitrided at* 550–560° *C.*—Diffraction spectra from the surface and from points at an increasing distance below the surface are reproduced in Fig. 8 (Nos. 1–10), and show the changes which occur in passing from the surface through the nitrided layer to the core. The spectrum given by the surface itself consists of lines which have the relative positions associated with a face-centred cubic structure, the side of the unit cubic cell being 3·65 Å. The positions of the lines agree closely, although not perfectly, with those in the spectrum of the γ' phase Fe_4N. The other possible states of combination of nitrogen with the metals present give spectra which differ widely from the above. It is concluded that the slight difference between the observed lines and those from pure Fe_4N is of the type to be expected from the partial substitution of the iron atoms in the pure lattice by chromium and nickel atoms. The surface material, therefore, possesses the structure of Fe_4N, but would probably be more accurately represented by $(FeCrNi)_4N$ owing to the presence of the other metals in solution. The complex nitride may also contain the tungsten in its composition. Photographs Nos. 1, 2 and 3 indicate the same structure as that found at the surface, but there is a marked broadening of the spectral lines in No. 3. The effect is shown more particularly by the lines at the right-hand side of the photograph; these lines, having been diffracted through large angles, are most sensitive to any changes affecting the definition, and, as a result of the broadening, they become weak and tend to disappear from the photograph. The broadening of the lines indicates the presence of distortion in the atomic lattice of the γ' Fe_4N structure; the distortion may be due to a lower nitrogen content in the phase, in which the proportion of metal to nitrogen atoms is greater than the 4 : 1 ratio required for the $(FeCrNi)_4N$ structure, occasional nitrogen atoms being lacking. At a depth below 0·005 mm. the instability of the γ' structure, due to a decrease in the nitrogen content, leads to a new manner of association of the atoms. This is shown in Nos. 4–10. No. 4 shows the structure at 0·035 mm. below the surface; the main spectral lines exhibit, in comparison with No. 3, a marked shift to the right, and indicate, although they are diffuse, a transition to a new structure. The latter corresponds to that of the austenite of the original steel, which is face-centred cubic with an edge of 3·56 Å. Nos. 5–10 show the same lines as No. 4, but the lines which have disappeared in the right half down to approximately 0·085 mm. depth become increasingly well defined, and culminate in the sharp spectra of Nos. 9 and 10, which correspond with the core material.

The diffuse spectra indicate that the austenite appears in a highly distorted form within the nitrided layer, and becomes less distorted as the nitrogen content diminishes towards the core.

Discussion of Results.

The iron nitride compounds found in nitrided ingot iron agree substantially with those described by Hägg and others.[9, 10, 11, 12, 17] The microstructure shown in Fig. 9 is that found after nitriding at 550–560° C., and the compositions of the various phases are revealed by the results of the X-ray test. The dark-etching surface layer is the ε phase, and contains approximately 9·5% of nitrogen; it was difficult to preserve it intact for microscopical examination owing to its brittle nature. It appears to be a mass of finely dispersed nitride particles. Immediately below this surface layer is the layer of the γ' Fe_4N compound, which is coloured a yellow-brown on etching, and extends as a thick layer around the grain boundary in the zone near the surface. The γ' phase is the same material as the so-called nitride "needle" which forms in the grain itself, while the finely dispersed nitride particles, usually found associated with the "needles" in steels with a high nitrogen content, probably belong to the high-nitrogen ε phase, because they are similar to the particles found in the extreme edge. This is shown in Figs. 9 and 10, the latter representing the high-nitrogen zone near the surface, in which are found coalesced Fe_4N at the grain boundaries, plates of Fe_4N, and finely dispersed particles in the grains. The nitride inclusions are numerous and persist to a considerable depth in the nitrided iron; the lines due to nitride in the X-ray diffraction pattern are only well defined, however, in the zone near the surface. Where the inclusions are deposited in the ferrite grains, the spectrum lines are only faint, and are apparently lost in the general background of scattering from the iron crystals. The increased hardening of the iron is practically negligible. The X-ray test gave sharp spectral lines, even in the surface layers (Fig. 3), hence showing an absence of distortion. The numerous inclusions of iron nitride have evidently resulted in breaking up the iron crystals without distorting them.

Some light on the effect of nickel in the nitrided austenitic steels is provided by the examination of high-nickel steels. Fig. 11 shows the structure of a low-carbon 8% nickel steel after nitriding at 550–560° C., the outside layer being composed of the ε phase, which is followed by a thin layer of Fe_4N. The X-ray test on nitrided filings of Invar (36% nickel) showed that only the iron portion of the alloy is converted to nitride, although the nickel still retains some of the iron in solid solution (Fig. 5). Nitriding tests on these and other nickel steels prove that the amount of nitrogen absorbed by the steels progressively decreases with an increased nickel content, until, in a sample of nickel itself, the absorption is negligible. The above evidence that a nitride of nickel in crystalline

form is not found in the X-ray spectra, points to the fact that nickel does not form a separate nitride. No appreciable hardening results, therefore, from the nitriding of either ferritic or austenitic nickel steels.

Practically all commercial nitriding steels contain chromium as an essential element. In the high-chromium alloys examined, the greatest depth of hardening is obtained in the 13% chromium steel, while in the austenitic steels the depth of hardening steadily becomes less as the nickel content of the steels increases (Fig. 2). It also becomes difficult to introduce nitrogen into an austenitic steel when the nickel content is above a certain value (Table III.).

Typical microstructures of nitrided chromium steels are illustrated in Figs. 12–14. The nitrided layer is readily revealed on etching with dilute alcoholic nitric acid, which does not affect the core. The structure of the austenitic steels is obtained in the same manner, but the time of etching is longer. The resistance to acid is, therefore, lower in the nitrided layers than in the original steels. The 13% chromium steel (Fig. 12) contains an outside ε phase, followed by an area which contains the γ' phase Fe_4N, together with CrN, while the spectral lines corresponding to the core metal are obtained below a depth of 0·08 mm. The depth-hardness curve in Fig. 2 shows that the ε phase is comparatively soft, and the greatest hardness occurs where the high-nitrogen phase is practically removed. The nitrides formed, CrN, &c., are themselves highly distorted in structure, and, when present with the alloy, appear to induce considerable distortion in that structure also. The crystalline structure of the alloy below the nitrided layer is, however, normal and perfect. The hardness of the layer is evidently associated with the distortion shown. The microstructure within the layer is that of fine-grained sorbite (Fig. 13). The withdrawal of some chromium from solid solution in the iron as CrN has changed the character of the nitrided layer and decreased its resistance to acid attack. The same characteristic is also shown by the nitrided 17% chromium steel (Fig. 14), but the depth of case is less.

While the hardness of the austenitic steels is due to the chromium content, the depth of hardening is controlled by the amount of nickel present. An 18/8 chromium-nickel steel is readily transformed partially to the α-iron state by cold-work; the same effect is found within the nitrided layer of the steel. Below the surface of nitrides (Fig. 7), a highly diffused spectrum of α-iron is produced, and this coincides with the maximum hardening found in the steel (Fig. 2). The γ–α iron inversion probably occurs as a result of some chromium being removed from solid solution, as nitride, in a finely dispersed form; this depletes the austenite of the chromium necessary for its existence. Martensite, which should form, is changed into sorbite by the tempering action of the process. The microstructure of the nitrided layer is shown in Figs. 15 and 16, and is of the same type as that found in the nitrided chromium steel. The effect is equivalent

to "internal cold-work," which changes the constitution of the alloy. The α-iron formed contains nickel and possibly some chromium in solution, as shown by the high value for the estimated size of the elementary cube (2·88 Å). The edge is revealed on etching with dilute nitric acid, the core being unaffected.

The nickel-chromium-tungsten heat-resisting steels, *KE*965 and Era *ATV*, contain a stained edge on etching with dilute nitric acid. Typical microstructures are given in Figs. 17–20, after nitriding at 550–560° C., and they show a smaller depth of case than in the previous steels. The thin layer of copper deposited on the steel prior to nitriding can be seen as a coloured band on the surface (Fig. 18). It does not form a nitride and does not assist nitrogen penetration. The structure is that of austenite and free carbides, which, although of the same character as the original steel, is now revealed by attack with dilute acid. An increased rate of attack by acids on steel containing an appreciable amount of nitrides is also well known in the structure of mild steel welds.

Handforth [14] has stated that a nitrided austenitic-steel valve stem is prone to attack by the products of combustion of a fuel containing lead tetra-ethyl, although the steel is almost unaffected if kept well lubricated. One of the most widely used austenitic valve steels in aero engines is the heat-resisting steel No. 10 (*KE*965 steel). The X-ray test on the structure of the nitrided layer indicates that the surface contains a complex nitride, which corresponds approximately to $(FeCrNi)_4N$; the latter also probably contains the tungsten in solution. The surface layer of copper (Fig. 18) was not definite in the X-ray spectrum, owing to the very narrow band and to the fact that it possesses approximately the same size of unit cell as the nitride formed. The greatest hardness is shown in the zone just below the surface, where there is evidence of extremely diffused lines in the X-ray spectrum. The diffuse spectra (Fig. 8) indicate that the austenitic structure exists within the nitrided layer in a distorted form. There is no evidence for the presence of α-iron. The austenite becomes less distorted as the nitrogen content diminishes towards the core, where the structure is free from distortion, as indicated by the sharp spectra found. Wood [15] also found a distorted α-iron lattice, as revealed by spectra of a very weak and diffuse nature, in a chromium-aluminium (Nitralloy) steel. The greater difficulty in hardening Era *ATV* steel is due to the comparatively inert effect of the high nickel content (26%), which not only restrains the formation of the nitrides of chromium, &c., but also dissolves in the crystal lattice of the nitride formed. When the iron is reduced, and the nickel content is raised to the composition of nichrome, and to that of nickel itself, the hardening capacity of the material is destroyed. Although the evidence is indirect, it is probable that the observed distortion found in the high-chromium and austenitic steels is due to the presence of highly-dispersed nitrides of chromium, &c., of an

almost amorphous size. The presence of CrN was detected in the 13% chromium steel, but the lines were very weak and indistinct, while in the austenitic steels the presence of nitrides could not be found, except in the extreme surface. Owing to the extreme distortion of the iron lattice, however, which must be caused by their presence, the crystallites of alloy nitrides are of such a fine size that they are almost equivalent to a solution of foreign matter in the lattice. The aggregates of nitrides, trapped in the crystal lattice, make the latter irregular and cause a distorted grain, which is revealed by an *extraordinary* diffusion of the X-ray spectra. Large particles of nitrides, as found under the microscope in ingot iron, result merely in the breaking-up of the iron crystals, without distorting them. The sharp iron diffraction lines in the X-ray pattern of ingot iron are in striking contrast to the broad diffuse lines of the distorted α- and γ-iron found in the alloy steels.

The austenitic steels become slightly magnetic after nitriding, due to the magnetic character of the nitrided layer, the core remaining practically non-magnetic. This is due to the presence of nickel in the lattice of the nitrides formed, and to the high degree of distortion of the grain, which, in the case of the 18/8 chromium-nickel steel, cause the formation of α-iron.

Summary.

(1) Good results have been obtained by nitriding high-chromium and austenitic steels after treatment of the surfaces by copper-plating and with phosphate reagent. High-chromium steels are rapidly attacked by the latter, and the time of treatment must be carefully regulated.

(2) The nitriding of certain high-chromium and austenitic steels at a temperature greater than 550° C. results in a marked decrease in hardening. When the nickel content of austenitic steels is raised, as in the heat-resisting steels, a nitriding temperature of 600° C. is also satisfactory. Higher temperatures are deleterious for all steels.

(3) The constitution of the nitrided layer of the various steels has been found by means of an X-ray examination. The surface consists of the nitrides of iron and of the alloying elements, the composition of which has been ascertained. The maximum hardening effect is found below, and is associated with extra-ordinarily diffused spectra of the alloy, indicating great distortion of the atomic lattice.

(4) Nickel does not form a separate nitride, but it is probable that the element dissolves in the lattice of the nitrides of iron and chromium by a replacement of atoms. Nickel, therefore, does not cause nitride-hardening, which is due, in the steels examined, to the presence of finely-dispersed nitrides containing chromium of an almost amorphous size.

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SOME ALLOYS FOR USE AT HIGH TEMPERATURES.

PART IV.—THE CONSTITUTION OF THE ALLOYS OF NICKEL, CHROMIUM AND IRON.*

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(Figs. 17 to 55 = Plates XVIII. to XXIV.)

SUMMARY.

The paper consists of a description of the work carried out at the National Physical Laboratory on the constitution of the alloys of nickel, chromium, and iron, together with a review of the literature up to September, 1936. For convenience, the paper is divided into four sections relating to (*a*) chromium-iron alloys, (*b*) nickel-iron alloys, (*c*) nickel-chromium alloys and (*d*) nickel-chromium-iron alloys. New experimental work is described in Sections B, C and D. This comprises a determination of the solidus of the nickel-iron system, re-investigations of the liquidus and solidus temperatures and solid constitution, *at temperatures above* 800° C., of the nickel-chromium alloys and of the nickel-chromium-iron alloys containing up to 50% of chromium. The phase diagram of the ternary alloys is illustrated by horizontal sections.

The work described in this paper was carried out for the Committee on the Behaviour of Materials at High Temperatures appointed by the Metallurgy Research Board.

The following account reviews the literature until September, 1936, and gives a description of the work carried out for the Committee. For convenience the report is divided into four Sections:

A.—The constitution of the chromium-iron alloys.
B.—The constitution of the nickel-iron alloys.
C.—The constitution of the nickel-chromium alloys.
D.—The constitution of the nickel-chromium-iron alloys.

A.—The Constitution of the Chromium-Iron Alloys.

A full bibliography of this system was given in 1931 by Adcock,[1] whose constitutional diagram has been used in the construction of

* Communication from the National Physical Laboratory, received July 10, 1937.

For Parts I. and II. see *Journal of the Iron and Steel Institute*, 1930, No. I., p. 225, for Part III., *ibid.*, 1931, No. I., p. 313.

Dr. C. R. Austin, formerly a member of the staff and now Associate Professor of Metallurgy at Pennsylvania State College, was connected with Section C of this paper.

the ternary nickel-chromium-iron diagram. Since that date papers by Wever and Jellinghaus,[2] Eriksson,[3] and Jette and Foote [4] have suggested the probable slow formation of a compound phase at low temperatures at the composition FeCr. A revised diagram of this system has recently been put forward by Hansen [5] in "Der Aufbau der Zweistofflegierungen," from which Figs. 1 and 2 are taken. Fig. 1 indicates the position of this possible FeCr field in relation to the other changes in the diagram and shows the suggested complex nature of the constitution at low temperatures. Fig. 2 is a record of the experimental data relating to the γ-loop and the magnetic changes.

No experimental work has been undertaken on this system for the Committee on the Behaviour of Materials at High Temperatures.

B.—The Constitution of the Nickel-Iron Alloys.

The nickel-iron system has received consideration from a large number of workers, as is indicated in Desch's [6] recent review of published information relating to the constitution of these alloys. All the recent investigators are agreed that there are two solid phases at temperatures immediately below the solidus, the δ and γ solid solutions, respectively body-centred cubic and face-centred cubic structures. Of these, the δ phase occurs only in iron-rich alloys, whilst the γ phase has a wide range of homogeneity; between about 900° and 1400° C. the range is 0–100% iron. The liquidus passes through a minimum at about 60% nickel—*see* Fig. 3, which is taken from Hansen,[5] and is based on the results of Hanson and Hanson,[7] Hanson and Freeman,[8] Kasé,[9] Vogel [10] and Bennek and Schafmeister [11]; of these authors, all except Vogel are in fair agreement with regard to the form of the liquidus and the extent of the δ phase field.

As will be seen from Fig. 3, the A_3 transformation of iron is steeply depressed by the addition of nickel. Fig. 4, also taken from Hansen's review,[5] indicates the considerable degree of hysteresis exhibited by this change; the hysteresis is, indeed, so great at the lower temperatures that it is difficult to assess the equilibrium position of the two-phase field between the γ and α phases. Another change known to occur in these alloys in the solid state is a magnetic transformation derived from the magnetic change points of nickel and iron. The change in the nickel-rich alloys occurs at a maximum temperature in the alloy containing 70% of nickel and is regarded by some writers, notably Broniewski and Smolinski,[12] as an indication of the existence of a compound $FeNi_2$ soluble in nickel and in γ-iron. Jette and Foote,[13] on the other hand, have not found X-ray evidence of the existence of a compound or of an "ordered" arrangement.

In the construction of the ternary nickel-chromium-iron diagram, use has been made, after correction of the assumed melting point of

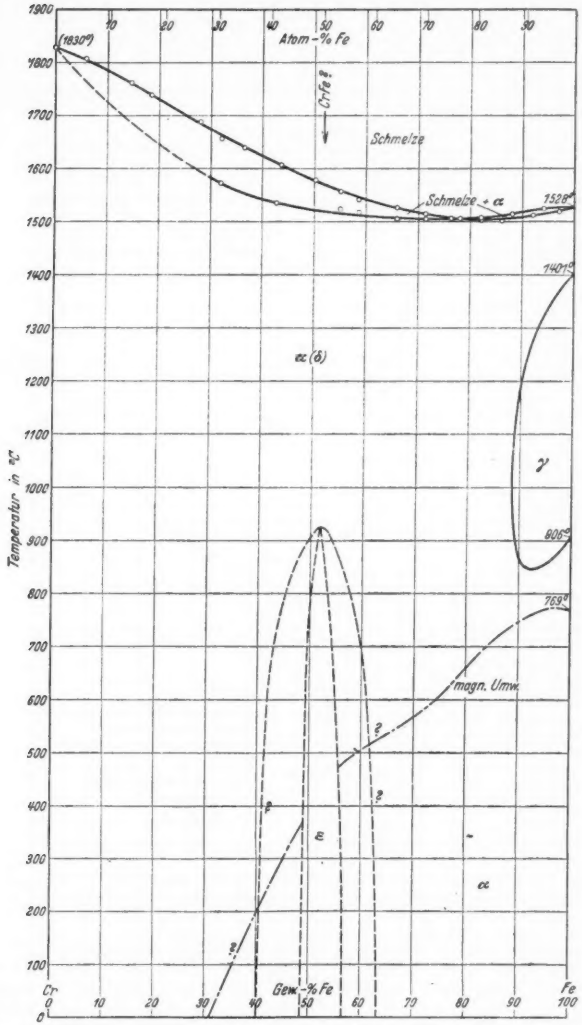

FIG. 1.—The Constitution of the Chromium-Iron Alloys (Hansen, "Der Aufbau der Zweistofflegierungen," Fig. 229, p. 530).

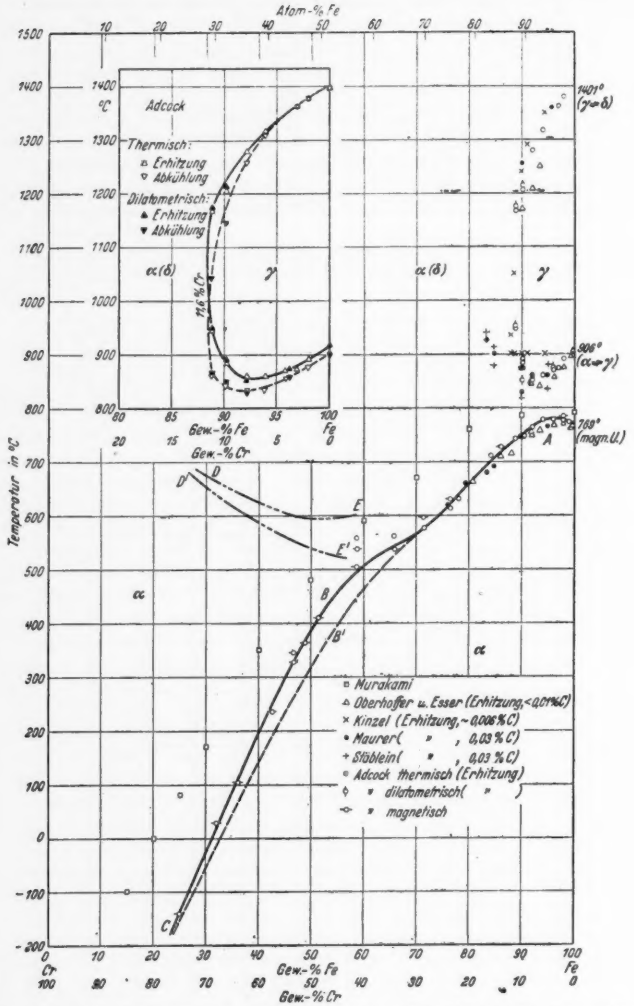

FIG. 2.—The Transformations in the Chromium-Iron Alloys (Hansen, " Der Aufbau der Zweistofflegierungen," Fig. 228, p. 525).

iron to 1527° C.,[14] of the values obtained by Hanson and Freeman for the liquidus temperatures and the position of the peritectic reaction line. The peritectic reaction is considered to occur at 1499° C. in alloys with 3–5·5% of nickel. The composition of the peritectic γ phase has been assumed to be 4% of nickel. The thermal

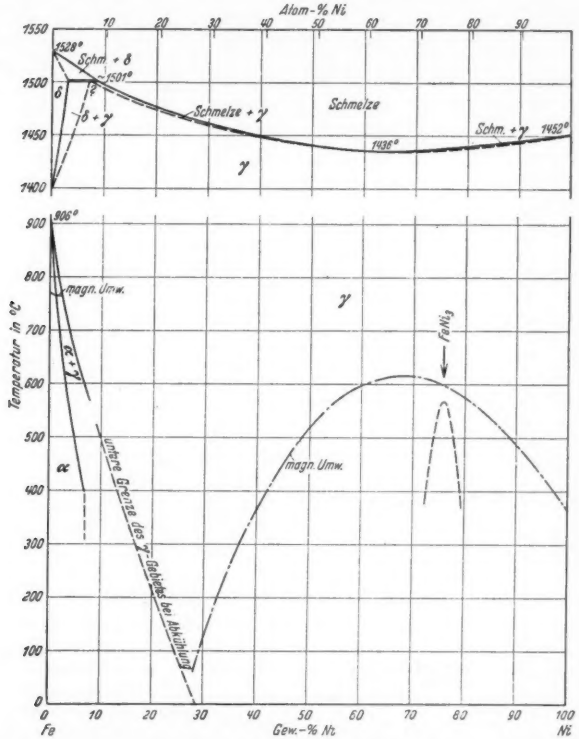

FIG. 3.—The Constitution of the Iron-Nickel Alloys (Hansen, "Der Aufbau der Zweistofflegierungen," Fig. 281, p. 697).

data of Hanson and Freeman did not indicate the position of the solidus curve, but Kasé reported that the solidus curve passed through a minimum some 6° C. below the lowest liquidus temperature.

It was decided in this research to determine the solidus by quenching experiments. Nine alloys were made up as small melts *in vacuo* in the high-frequency induction furnace from specially selected

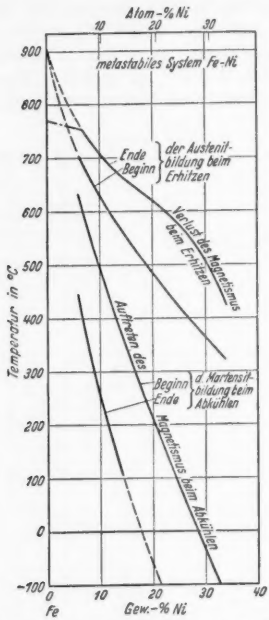

FIG. 4.—The Transformations in the Iron-Nickel Alloys (Hansen, "Der Aufbau der Zweistofflegierungen," Fig. 282, p. 699).

TABLE I.—*Nickel-Iron Alloys.*

Alloys and Analyses. (N = Ni; F = Fe.)	Results of Heat Treatment. Constitution.	
	γ + liquid at ° C.	γ at ° C.
$N90F10$ Ni 90·0%, Fe 10·3%, Si 0·05%, C 0·015%	1435, 1429	1431, 1425
$N80F20$	1425, 1420	1416
$N70F30$	1425, 1414	1420, 1411
$N60F40$	1434	1416
$N50F50$ Ni 49·4%, Fe 51·1%, Si trace, C 0·009%	1437, 1434	1420
$N40F60$	1437, 1436	1432
$N30F70$ Ni 30·2%, Fe 69·8%, Si trace, C 0·005%	1440	
$N20F80$	1450	1445
$N10F90$	1470	1457

high-quality nickel shot and electrolytic iron* which had been purified by treatment in hydrogen while molten. These melts were allowed to solidify in the crucibles *in vacuo*. The nominal compositions of the alloys together with analyses in three instances are given in Table I. The ingots were given prolonged annealing treatments to remove coring, after which pieces were maintained for 15 min. at temperatures near the liquidus and quenched in cold water. The microstructure was then examined after polishing and etching. The results of the examination are included in Table I., whilst Fig. 5 indicates the temperatures at which liquid was thought first to be formed. The curve at present determined, like that of Kasé, passes through a minimum below that of the liquidus. Theoretical considerations indicate that the solidus and liquidus should meet at the temperature which is a minimum in the diagram. The present determination of the solidus has been used in the construction of the ternary diagram.

C.—The Constitution of the Nickel-Chromium Alloys.

In view of the importance of these alloys from the standpoint of high-temperature service, a complete redetermination of the system was put in hand in 1926, but on account of the other work for the Committee the matter has not been continuously pursued. At that time the constitution of the binary alloys of nickel with chromium was imperfectly understood. The early work of Voss [15] had shown that the liquidus curve of the equilibrium diagram consisted of two branches falling from the then accepted melting points of nickel and chromium to approximately 1290° C. at a composition of about 42% nickel. At this composition he detected a eutectic-like microstructure, a fact which has, however, been ignored in his published diagram. The X-ray work of

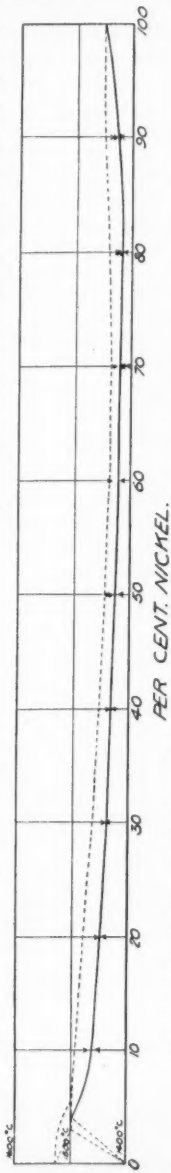

Fig. 5.—The Solidus of the Iron-Nickel System. Hanson and Freeman's results for the liquidus and the upper limits of the δ phase are shown by dotted line.

* Carbon 0·005–0·01%, silicon trace–0·01%, phosphorus 0·003–0·015%, sulphur trace, manganese trace, copper trace–0·006%, nickel trace–0·02%.

Bain [16] indicated lattices of the nickel and chromium types at the ends of the system and a range of duplex structures between.

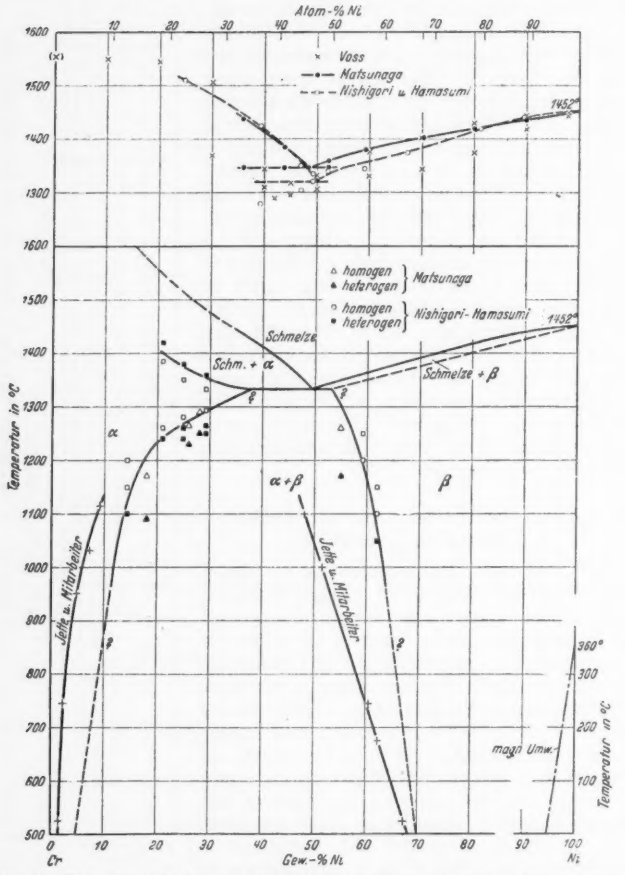

FIG. 6.—The Constitution of the Nickel-Chromium Alloys (Hansen, "Der Aufbau der Zweistofflegierungen," Fig. 231, p. 541).

Phebus and Blake [17] showed that the nickel lattice persisted to 63% of chromium.

The existence of a eutectic was confirmed by Blake [18] and finds support in the photomicrographs published by Smithells,

Williams and Avery,[19] in the light of which Pilling and Kihlgren[20] put forward a tentative constitutional diagram indicating a eutectiferous series with terminal solid solubility. At that date no certainty was felt as to the variation with temperature of the boundaries of the single-phase fields, as much of the work had been carried out on alloys which were certainly not in equilibrium.

Five papers have been published more recently which have served to indicate the limits of the various fields. These papers are those of Nishigori and Hamasumi,[21] Tasaki,[22] Wever and Jellinghaus,[23] Matsunaga[24] and Jette, Nordstrom, Queneau and Foote.[25] The workers named in references 21–24 above are agreed on the existence of a eutectic alloy melting at 1320–1346° C., and all but Tasaki give a composition of 50–51% of chromium. There was considerable diversity of opinion amongst these writers as to the melting point of the chromium-rich alloys (in no case does the experimental work extend to chromium contents higher than 70%) and in the limits of the solid solution fields—*see* Fig. 6, which is again taken from Hansen's review.[5] The melting point of chromium was found by Adcock[1] to be 1830° C.

Jette and his collaborators[25] carried out experiments in which powders of 16 alloys made under hydrogen from electrolytic nickel and chromium were annealed *in vacuo* at temperatures between 524° and 1113° C., quenched and examined by X-ray methods followed by chemical analysis. The solubility of nickel in chromium is shown to be rather small at the lower temperatures, but to increase to 9·3% by weight at 1113° C.—the highest temperature employed—a value which is in fair agreement with that obtained by Nishigori and Hamasumi,[21] but is less than those given by Matsunaga[24] or by Wever and Jellinghaus.[23] Jette and his co-workers' curve for the solid solubility of chromium in nickel shows a much higher solubility than any previous diagram, and indicates a linear increase in solubility with temperature from 32·4% of chromium at 524° C. to 52·2% of chromium at 1113° C. They point out that this last-named chromium content is higher than that generally accepted as the composition of the eutectic.[21,23,24] This suggests a retrograde change of solubility at higher temperatures if the determinations of the liquidus and Jette, Nordstrom, Queneau and Foote's phase boundary are both correct. It is, however, doubtful whether the powders examined by these workers had reached equilibrium, and some doubt also attaches to the method employed in converting parameter values to solid solubility values. The present research indicates a normal continuous fall of solid solubility between the eutectic temperature and 800° C., *see* Fig. 7.

In view of the slow rate of diffusion of chromium in nickel, similar to that in the nickel-iron alloys, the experimental work carried out on this system for the Committee has comprised a complete redetermination of the equilibrium diagram at temperatures above 800° C. by thermal analysis and micrographical methods. A

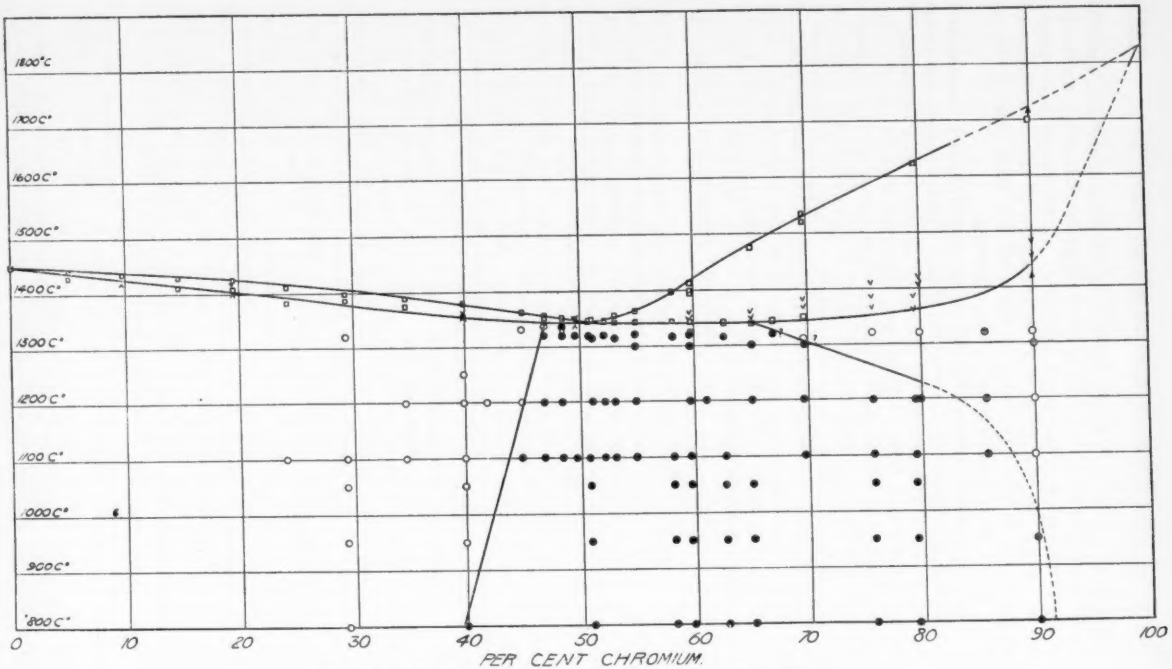

FIG. 7.—The Constitution of the Nickel-Chromium System.

preliminary survey was made with the purest materials commercially available, namely, shot nickel and selected thermit chromium, containing less than 1% of iron plus aluminium plus silicon, before a more detailed study using deoxidised electrolytic chromium was undertaken. In the preliminary experiments the materials were melted in pure alumina crucibles in the induction furnace *in vacuo*. When the alloy was thoroughly molten the furnace was opened and a 5/20 platinum-rhodium thermocouple in a magnesia sheath was inserted in the melt and a cooling curve taken. These preliminary experiments indicated that the liquidus falls slowly from the melting point of nickel to a eutectic at 1330° C. and 50% chromium, and then rises steeply to 1528° C. at 70% and 1624° C. at 80% chromium.* A 60% chromium alloy made from electrolytic chromium, and included in this series as a check on the effect of the impurities present on the liquidus temperatures, began to freeze at 1420° C. This value does not differ from that obtained with the alloy made from thermit chromium. The high temperatures at which the chromium-rich alloys begin to solidify were at that date somewhat surprising, since the melting point of chromium was then thought to lie some 200° lower than the value now accepted (1830° C.).[1]

The compositions of the alloys employed in the main investigation are indicated in Table II., which includes chemical analyses, arrests on heating and cooling curves and the effect of heat treatment on the microstructures. The alloys studied contain up to 90% of chromium, and are separated by intervals of roughly 5%, except between 30 and 65% of chromium when the spacing is generally 2½%; between 45 and 55% of chromium, alloys were made at 1% intervals. These alloys were made from high-purity nickel shot and electrolytic chromium prepared at the National Physical Laboratory.[1] The nickel shot contained 0·006–0·01% of copper, 0·05–0·07% of iron, 0·08% of carbon, 0·01% of sulphur and traces of silver and magnesium. These materials were first given a refining treatment by heating them in an atmosphere of hydrogen freed from oxygen and water vapour. Two-hundred gramme melts were then made in hydrogen in the induction furnace. Alloys of high chromium content were melted *in vacuo* and given a final prolonged treatment in hydrogen before allowing them to solidify in the crucible. This was necessary to overcome the increased cooling at high temperatures set up by the hydrogen atmosphere.

In Table II. the analyses of thermal ingots are prefixed by a *T*, and specimens for solid constitution by an *S*. The *T* analysis samples were prepared after the thermal curves had been taken. Spectrographic analyses of one of the alloys, *N*43*C*57, indicated a heavy trace of calcium and very faint traces of copper, magnesium,

* These compositions are nominal; the analysis of the last alloy was 76·5% chromium, 20·26% nickel, 0·47% iron, 0·16% silicon, 1·86% insoluble, mainly alumina.

FIG. 7.—The Constitution of the Nickel-Chromium System.

TABLE II.—*Nickel-Chromium Alloys.*

Alloys and Temperatures of Thermal Arrests. °C. *L* = liquidus. *S* = solidus. (*N* = Ni; *C* = Cr.)	Chemical Analyses. *S* = on material for solid constitution. *T* = after thermal point determination. In. = insoluble residue.	Constitution after Heat Treatment (Summary). *M* = liquid. hr. = hour. d. = day. Temperatures in °C.	
*N*95*C*5			
1443 *L*, 1430 *S*			
*N*90*C*10	*S* Ni 90·28%, In. 0·18%,	$\gamma + M$	½ hr. 1426
1435 *L*, 1433 *S*	Cr 9·69%	γ	½ hr. 1420–1421
*N*85*C*15	*T* Cr 14·35%,		
1428 *L*, 1410 *S*	In. 0·12%		
*N*80*C*20	*S* Ni 80·44%, Fe 0·14%,	$\gamma + M$	½ hr. 1405–1415
1424 *L*, 1407 *S*	Cr 19·43%, In. 0·23%	γ	½ hr. 1400
*N*76*C*24	*T* Cr 23·8%,	γ	14 d. 1100
1410 *L*, 1382 *S*	In. 0·44		
*N*75*C*25		γ	1 hr. 1330
1410 *L*, 1401 *S*			
*N*70*C*30	*S* Ni 70·65%, In. 0·73%,	$\gamma + M$	½ hr. 1385
1396 *L*, 1386 *S*	Cr 28·75%	γ	21 d. 800; 1 hr. 1320
*N*65*C*35	*T* Ni 65·39%, Fe 0·11%	γ	14 d. 1100; 1 d. 1200
1387 *L*, 1374 *S*	Cr 34·34%, In. 0·16%		
*N*60*C*40	*S* Ni 60·34%, In. 0·63%	$\gamma + M$	½ hr. 1360
1377 *L*, 1355 *S*, 1251	Cr 39·12%, C 0·032%	γ	14 d. 950; ½ hr. 1356
		$\gamma + \alpha$	21 d. 800
*N*58*C*42		γ	7 d. 1200
*N*55*C*45	*S* Ni 55·16%,	γ	1 d. 1200; 1 hr. 1320
1361 *S*	Fe 0·01%	$\gamma + \alpha$	14 d. 1100
*N*53*C*47	*T* Ni 53·14%, In. 0·23%,	γ	¾ hr. 1335
1356 *L*, 1352 *S*, 1231	Cr 46·35%	$\gamma + \alpha$	14 d. 1100; 1 hr. 1320
*N*51*C*49			
1352 *L*, 1329 *S*, 943	*T* Ni 51·59%, Si 0·02%,	$\gamma +$	14 d. 1100; ¾ hr. 1335
	Cr 47·23%, In. 0·59%,		
	C 0·038%		
*N*50*C*50			
1349 *L*, 1339 *S*, 1256, 940	*T* Ni 50·45%, In. 0·65%,	$\gamma + M$	½ hr. 1347–1355
	Cr 48·7%	$\gamma + \alpha$	14 d. 1100; ½ hr. 1341
*N*49*C*51 (*A*)			
1345 *L*, 1129, 945	*S* Ni 49·26%, In. 0·75%,	$\gamma + \alpha$	21 d. 800; 1 hr. 1320
	Cr 50·01%		
*N*49*C*51 (*B*)	*T* Ni 48·96%,	$\gamma + \alpha$	3 d. 1200; 1 hr. 1315
1346 *L*, 935	Cr 50·47%, In. 0·28%		
*N*48*C*52	*S* Ni 47·94%, In. 0·30%,	$\gamma + \alpha$	14 d. 1100; 1 hr. 1320
1345 *L*, 948	Cr 51·58%		
*N*47*C*53		$\gamma + \alpha$	14 d. 1100; 1 hr. 1315
1354 *L*, 1343 *S*, 948			
*N*45*C*55	*T* Ni 45·19%, In. 0·29%,	$\gamma + \alpha$	14 d. 1100; 1 hr. 1320
1363 *L*, 1343 *S*, 952	Cr 54·3%		
*N*43*C*57	*T* Ni 41·90%, In. 0·46%,	$\gamma + \alpha$	21 d. 800; 1 hr. 1315
1397 *L*, 1344 *S*, 948	Cr 56·90%		
*N*40*C*60 (*A*)	*T* Ni 40·34%, In. 0·02%,	$\gamma + \alpha$	21 d. 800; 1 hr. 1320
1411 *L*, 1345 *S*, 1207, 951	Cr 57·93%, Si 0·02%		
*N*40*C*60 (*B*)		$\alpha + M$	½ hr. 1342–1356
		$\alpha + \gamma$	7 d. 1200
*N*39*C*61		$\alpha + \gamma$	7 d. 1200
*N*38*C*62	*S* Ni 37·34%,	$\alpha + \gamma$	21 d. 800; 1 hr. 1315
1340 *S*	Fe 0·04%		
*N*35*C*65	*T* Ni 34·96%,	$\alpha + M$	¼ hr. 1345–1355
1475 *L*, 1338 *S*, 948	Cr 62·16%	$\alpha + \gamma$	21 d. 800; 3 d. 1300
*N*33*C*67		$\alpha +$ tr. γ	1 hr. 1320
1342 *S*			
*N*30*C*70 (*A*)	*T* Ni 30·29%, In. 2·64%,	$\alpha + M$	¼ hr. 1363–1375
1519 *L*	Cr 67·07%	α	1 hr. 1310
		$\alpha + \gamma$	14 d. 1100; 3 d. 1300
*N*30*C*70 (*B*)			
1535 *L*, 1350 *S*, 953			
*N*25*C*75	*S* Ni 24·26%, Fe 0·04%,	$\alpha + M$	¼ hr. 1362–1405
953	Si 0·06%, C 0·041%	α	1 hr. 1320
		$\alpha + \gamma$	21 d. 800; 3 d. 1200*
*N*20*C*80 (*A*)	*S* Cr 79·37%	$\alpha + M$	¼ hr. 1360–1382
		$\alpha + \gamma$	21 d. 800; 3 d. 1200*

* Nitride needles in α phase.

TABLE II. (*continued*).

Alloys and Temperatures of Thermal Arrests. °C. *L* = liquidus. *S* = solidus. (*N* = Ni; *C* = Cr.)	Chemical Analysis. *S* = on material for solid constitution. *T* = after thermal point determination. In. = insoluble residue.	Constitution after Heat Treatment (Summary). *M* = liquid. hr. = hour. d. = day. Temperatures in °C.	
*N*20*C*80 (*B*)	*S* Ni 20·07%, Fe 0·08%, Si 0·06%	$\alpha + M$	½ hr. 1405–1415
		α	1 hr. 1320
		$\alpha + \gamma$	1 hr. 1200
*N*15*C*85	*S* Ni 14·31%, Fe 0·01%	α	1 hr. 1320
		α + nitride	14 d. 1100; 3 d. 1200
*N*10*C*90 (*A*) 1062, 924			
*N*10*C*90 (*B*)	*S* Ni 10·05%, Fe 0·04%	$\alpha + M$	½ hr. 1452–1479
		α	1 hr. 1200; ½ hr. 1425
		α + nitride	14 d. 950–1100
		$\alpha + \gamma$	21 d. 800
*N*10*C*90 (*C*)		α ($+ \gamma$ in cored areas)	3 d. 1300

sodium, vanadium and aluminium. Ingots for thermal analysis were made by remelting about 100 g. quantities in alumina crucibles in the induction furnace under hydrogen. Thermal curves were taken with a platinum-rhodium thermocouple protected by a sheath of vitreous silica, devitrified by previous heating in hydrogen, again in an atmosphere of hydrogen maintained within a glazed gas-tight muffle in a carbon-ring or Silit resistance furnace. It was found necessary to protect the sheath from attack by the alloys containing 60% and more of chromium with a coating of alundum cement. Under these conditions there was little evidence of contamination of the thermocouple.

The liquidus temperatures of the alloys of high chromium content could not be determined in this way, but the experiments afford some indications of the location of the curve; for example, an alloy containing 89% of chromium was heated to 1680° C. without the couple sheath sinking into the alloy, nor when the sheath was re-inserted in a hole drilled in the specimen was there any indication of complete melting up to 1675° C.

Confirmatory work, carried out by the optical methods described by Jenkins and Gayler,[14] showed that in the alloy containing 89% of chromium, the liquidus temperature had not been reached at 1700° C. This is consistent with a melting point of 1830° C. for chromium.

The results of thermal analysis are included in Table II. and Fig. 7. In this figure, the liquidus curve consists of two branches, which meet at a eutectic point in the centre of the diagram. The lowest observed liquidus arrest was at 1345° C.; this is given by each of three alloys containing 50·4, 50·8 and 51·8% of chromium, none of which showed a second arrest. The thermal curves usually gave good indications of the solidus temperatures. The solidus curve for the nickel-rich alloys is separated from the liquidus by no more than 10° C. at 30% chromium. The solidus arrests for 10

alloys containing 49–65% of chromium are at 1343° C. (average). Beyond this composition the solidus temperatures indicated by the thermal curves rise slowly to 1350° C. for an alloy containing 70% of chromium.

In addition to the arrests corresponding to the liquidus and solidus, the thermal curves of alloys containing considerable proportions of chromium exhibit small arrests on cooling at about 950° C. and on heating at about 1100° C. These arrests may be a consequence of a somewhat sharp change in the solid solubility of nickel in chromium.

The solidus temperatures were also determined by microscopic examination of specimens first annealed *in vacuo* for 3 days at 1200° C. to remove coring, then reheated for either 15 or 30 min. at a temperature near that of the solidus arrest of the thermal curve, and finally quenched in cold water. These treatments are summarised in Table II., which gives the extreme ranges of temperature at which each type of microstructure was found. In the final experiments on the nickel-rich alloys, the specimens were heated in an atmosphere of nitrogen in a Silit resistance furnace. The solidus determinations for the chromium-rich alloys were carried out by means of a vertical Pythagoras tube passing through a carbon-ring furnace. An atmosphere of hydrogen was maintained within the Pythagoras tube, the thermocouple being protected by a sheath. The solidus temperatures determined by quenching are indicated in Fig. 7. These experiments confirm the thermal evidence of the form of the solidus and show that the rise of the solidus curve of the chromium-rich alloys continues slowly to 1430° C. at 89% chromium. Beyond this point the curve becomes much steeper, and finally reaches a temperature of 1830° C. at 100% chromium. In these quenching experiments the eutectic temperature was determined as lying between 1338° and 1342° C., confirming within 5° C. the indications of the thermal curves. The microstructures of the two alloys *N*70*C*30 and *N*10*C*90 (*B*), as quenched from a temperature near the solidus, are reproduced in Figs. 17 and 18.

The solid constitution of these alloys was determined by microscopical examination of specimens taken from the induction-furnace ingots and subjected to a series of vacuum annealing treatments. The alloys were first given a homogenising annealing, in which specimens were maintained for 18 hr. at 1250° C. and then heated for 1 hr. at 1320° C. (1315° C. in some cases) and quenched. After this treatment specimens were reheated *in vacuo* for 3 days at 1200° C., 14 days at 1100°, 1050° and 950° C., and 21 days at 800° C. After the initial homogenising treatment, alloys of low and intermediate chromium contents were found to be free from coring. Where cast material was subjected to heat treatments of 14 days' duration at such temperatures as 1100° and 1000° C. without prior homogenising, it was found that the initial dendritic segregation of the ingot had not been completely eliminated. The original

lamellar structure of the eutectic alloy persists after 21 days at 1000° C., but the eutectic is spheroidised in 14 days at 1100° C. The alloys of high chromium contents needed even more drastic annealing to eliminate coring completely. One of the major difficulties in the constitutional study of these alloys arises from the slowness with which equilibrium is attained even at the highest temperatures; this, coupled with the known reactivity of atmospheric nitrogen with the chromium-rich alloys, necessitates prolonged annealing *in vacuo* at elevated temperatures. Study of the alloys of the highest chromium contents is at present incomplete, largely because refractories have not been found in which the necessary prolonged annealing at temperatures above 1350° C. could be carried out *in vacuo*.

The microstructures of these specimens and those employed in the solidus determinations were developed by etching electrolytically in a mixture of 3 parts of glycerol, 2 parts of hydrochloric acid and 1 part of nitric acid, according to the method of Vilella.[27] This etching treatment was more reliable than etching by successive dipping in hydrochloric and nitric acids and electrolytic etching in acetic acid. Only two constituents are observed in these alloys, namely, a nickel-rich solid solution and a chromium-rich solid solution. These are referred to as the γ phase and the α phase, since the nickel and chromium lattices are isomorphous with those of γ- and α- or δ-iron, respectively. In this way conflict with the nomenclature employed in Section D is avoided. The nickel-rich γ phase resembles γ-iron in that it frequently exhibits twins, whilst the chromium-rich α phase, like α-iron, sometimes shows a "sub-boundary" structure and also markings resembling Neumann lamellæ.

The results of the annealing treatments to determine the solid constitution of the alloys are given in Table II. and set out in Fig. 7, in which open circles represent alloys consisting after heat treatment of a single phase, and black dots those of duplex constitution. The duplex field is found to extend from 47 to 65% chromium at the eutectic temperature, and to increase in width with decreasing temperature.

A conclusion from earlier experiments (*see* Figs. 65 and 66 of reference 28) with cold-worked alloys made from a commercial grade of chromium is confirmed, namely, that the solid solubility of chromium in nickel at 800° C. lies below 40 but above 30%. Alloys containing more than 65% of nickel were found to be homogeneous after all the heat treatments at temperatures above 800° C. to which they had been subjected. The alloy *N*60*C*40 is homogeneous at a temperature of 950° C. and above, but duplex at 800° C., whilst *N*55*C*45 is homogeneous at 1200° C., but shows a small separation of the second constituent at 1100° C. The alloy *N*53*C*47 is homogeneous at 1335° C., but duplex at 1320° C., whilst *N*51*C*49 and alloys of somewhat higher chromium contents are duplex at all

temperatures from 800° to 1335° C. The microstructures referred to are illustrated in Figs. 19, 20, 21, 22, 23, 24, 25 and 26.

The course of the boundary of the nickel-rich γ phase is regarded as being well established by the experimental survey described above. The boundary of the chromium-rich α phase is not so closely determined by the work in its present form. As indicated in Fig. 7, it is clear that the alloys *N*30*C*70, *N*25*C*75, *N*20*C*80 and *N*10*C*90 are duplex in constitution at temperatures below 1300°, 1200°, 1200° and 800° C., respectively, *see* Figs. 27, 28, 29 and 30. The alloys *N*25*C*75 and *N*20*C*80 probably consist entirely of the α phase at 1320° C. As is, however, seen from Figs. 31 and 32, " skulls " of undissolved electrolytic chromium surrounded by oxide films are present in all these alloys of high chromium content, and may readily be confused with traces of the γ phase. The attainment of equilibrium in these alloys is extremely slow; for example, one of the ingots containing 90% of chromium exhibited a cored structure after annealing for 3 days at 1300° C.

Another feature of the chromium-rich alloys which rendered difficult the interpretation of the microstructures of chromium-rich alloys was the appearance of markings in certain of the annealed samples, or a second constituent in the form of needles, which lie along certain of the crystallographic planes of the α phase. An example of this effect is shown in Fig. 33, which represents the alloy *N*15*C*85 as quenched from 1200° C. Specimens of the alloy *N*15*C*85 annealed in a fair vacuum at a temperature of 1100° C. exhibit a lesser development of the same type of marking; the same applies to *N*10*C*90 annealed at 1300°, 1100° and 950° C., *see* Fig. 34. Figs. 28 and 29 show markings of the type referred to in the α phase of alloys of duplex constitution. The alloys exhibiting markings are indicated by hatched circles in Fig. 7.

It was apparent from the first that the markings observed might be due to one of the following factors :

(*a*) Separation of the γ phase during rapid cooling,

(*b*) the presence of a compound containing nitrogen, due to contamination, or

(*c*) twinning brought about during preparation of the specimen for microscopical examination, similar to Neumann lamellæ in ferrite.

The first of these explanations appeared somewhat improbable in the light of the " sluggish " nature of diffusion processes in the alloys. When the matter was investigated it became clear that the markings appear only in specimens containing appreciable proportions of nitrogen, which is apparently readily absorbed from the residual air contained in a partial vacuum. For example, the alloy, *N*15*C*85 as quenched from 1200° C. is heavily contaminated, containing 1·17% of nitrogen. *N*15*C*85 (1100° C.) is less affected, containing 0·13% of nitrogen. Analyses have also been made of *N*10*C*90 annealed at

1100° and 1050° C., giving values of 0·09 and 0·14% of nitrogen, respectively. Nitrogen determinations on four other specimens gave the following results:

*N*60*C*40	800° C. (Fig. 20)	0·01%
*N*30*C*70	1300° C. (Fig. 27)	0·07%
*N*25*C*75	1200° C. (Fig. 28)	2·34%
*N*10*C*90	800° C. (Fig. 30)	0·008%

These confirm the conclusion that the markings are caused by nitrogen penetration. Chemical analyses of nickel-rich nickel-chromium and nickel-chromium-iron alloys which had been subjected to prolonged heating in nitrogen-bearing atmospheres usually indicated low nitrogen contents, 0·02% or less, similar to those of the original ingots. There was, however, one exception, a seriously contaminated specimen of *N*55*C*45, in which 0·28% of nitrogen was found. On the whole, the effect of atmospheric nitrogen is less than on the iron-rich chromium-iron alloys studied by Adcock.[36] The chromium-rich nickel-chromium alloys, on the other hand, are extremely susceptible to attack. When such alloys are heated in air an outer rim containing about 5% of nitrogen, with a characteristic eutectic-like structure, and an inner zone of lower nitrogen content are formed. The inner zone exhibits a strong development of needle-like markings in certain crystallographic directions, identical with those shown in Figs. 27, 29, 33 and 35.

In this connection attention is also drawn to the results of preliminary heat treatments of the nickel-chromium alloys in nitrogen. These observations arise from a series of "solidus quenching" experiments on alloys of high chromium contents, in which nitrogen was used instead of hydrogen. The solidus temperatures were not appreciably affected by this treatment, but in the microstructure of the quenched specimens a strong development of markings following crystal planes was observed, a typical example of which is illustrated in Fig. 35. These markings closely resemble those shown in Fig. 33.

Exposure to air during annealing treatments at 900° and 1000° C. is found to modify the microstructures of the alloys of intermediate as well as high chromium contents. The ranges of homogeneity of the α and γ solid solutions were somewhat restricted by treatment in air as compared with annealing *in vacuo*, and an additional phase appears in alloys containing nickel and chromium in approximately the ratio of one atom to two atoms. The alloy *N*35*C*65 is the one which is most affected by the atmosphere; this becomes brittle and passive to etching.

As a result of the experimental survey described above, the liquidus and solidus curves are known up to about 80 and 90% chromium, respectively. The solid constitution at high temperatures has also been explored and the existence of only two phases in the system confirmed. The solubility of chromium in the nickel-

rich γ phase at these temperatures is found to be less than that indicated by Jette and his colleagues, but somewhat greater than that found by Nishigori and Hamasumi, *see* Fig. 6. The boundary of the chromium-rich α phase has not yet been determined precisely, but the indications tend to confirm the form suggested by Nishigori and Hamasumi. The diagram shown in Fig. 7 has been used as a basis of the ternary equilibrium diagram of nickel, chromium and iron discussed in Section D.

D.—The Constitution of the Nickel-Chromium-Iron Alloys.

In the binary alloys of iron with nickel the effect of nickel is to raise the temperature of the A_4 transformation of iron and lower that of the A_3 transformation, and so set up a continuous range of solid solutions of the face-centred cubic type (γ phase field). In the iron-chromium alloys, on the other hand, chromium lowers the temperature of the A_4 transformation and also at first lowers that of the A_3 transformation, yet afterwards raises it, setting up a closed γ phase field of limited extent, and a continuous range, outside this loop, of solid solutions of the body-centred cubic type by the joining of the δ and α phase fields. In the description that follows, the symbol α is used to denote this phase region in the ternary system, and no discrimination has been made between α- and δ-iron in the diagrams. It has also been found convenient to employ the rounded values 1400° C. and 900° C. for the temperatures of the A_4 and A_3 transformations of iron. More accurate values are 1401° C. and 906° C., according to Hansen.[5] It is apparent that in the ternary nickel-chromium-iron alloys the effects of nickel and chromium are opposed, the one tending to produce at all temperatures an extended γ phase field and the other a restricted γ phase field but extended α phase field.

It follows that the position of the phase boundaries will be markedly affected by change in temperature, so that a composition which at one temperature lies within the γ phase field may at both lower and higher temperatures pass into the duplex $\alpha + \gamma$ field or even to the homogeneous α phase. These impressions were strengthened by the early studies of Chevenard,[26] who examined the effects of chromium additions on the dilatometric anomalies, electrical resistivity and magnetic properties of nickel-iron alloys, so that it was possible to make a qualitative estimate of the mode of dependence of the structure upon the composition, even before the publication of the exploratory constitutional survey of Bain and Griffiths,[29] which was the only metallographical work on these alloys published at the time when the present investigation was begun, in 1926.

Bain and Griffiths found in the iron-rich alloys to which their investigation was confined, three main types of structure, namely, alloys crystallising in the body-centred cubic lattice (α), face-

centred cubic alloys (γ), and alloys of duplex structure; the extent of these phase fields was shown to vary with the temperature. When the alloys were subjected to prolonged annealing at rather low temperatures a " brittle constituent " separated from alloys lying near the possible compound FeCr, as is indicated in Fig. 8, which represents the constitution of these alloys at 900° C.

More recently, papers dealing with this system from a constitutional standpoint have been published by Tasaki,[22] Dean,[30]

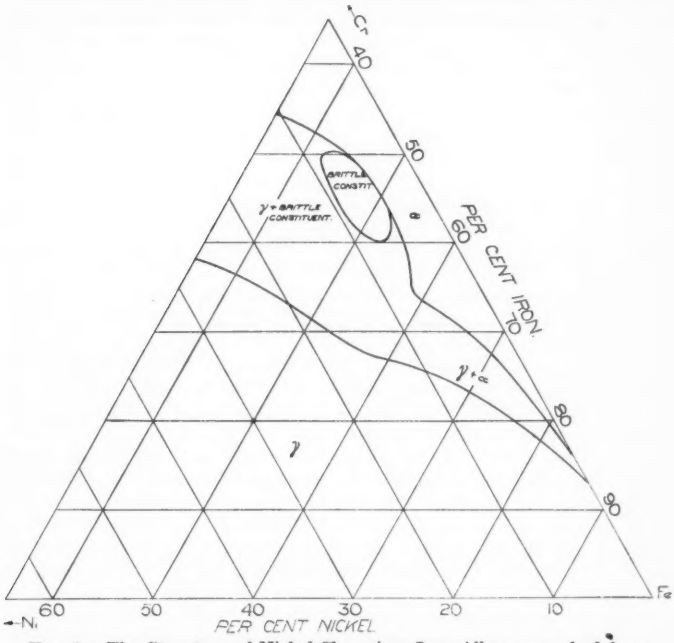

FIG. 8.—The Structure of Nickel-Chromium-Iron Alloys quenched from 900° C., after Bain and Griffiths.

Aborn and Bain,[31] Pomey and Voulet,[32] Krivobok and Gensamer,[33] and Wever and Jellinghaus,[23] while summaries of the present knowledge have been given by Krivobok[34] and Mellor.[35] Tasaki indicated that alloys consisting in the solid state of $\alpha + \gamma$ are formed by solidification from a region in which these two solid phases are in equilibrium with a liquid phase. This three-phase field runs from the peritectic horizontal in the nickel-iron system to the eutectic horizontal in the nickel-chromium system.

The work of Dean was concerned mainly with the electrical and

magnetic properties of the ternary alloys, but his investigations included X-ray analyses of a number of the alloys, and indicated the areas occupied by the α and γ fields in the system, but no description is given of the heat treatments to which these alloys had been subjected. Aborn and Bain restated the conclusions reached by Bain and Griffiths, and extended their investigation to alloys containing carbon in addition to nickel, chromium and iron. Pomey and Voulet classified the fields into which the ternary diagram is divided into nine areas according to the stable or metastable occurrence of the α or γ solid solutions and the possibility of changes in the

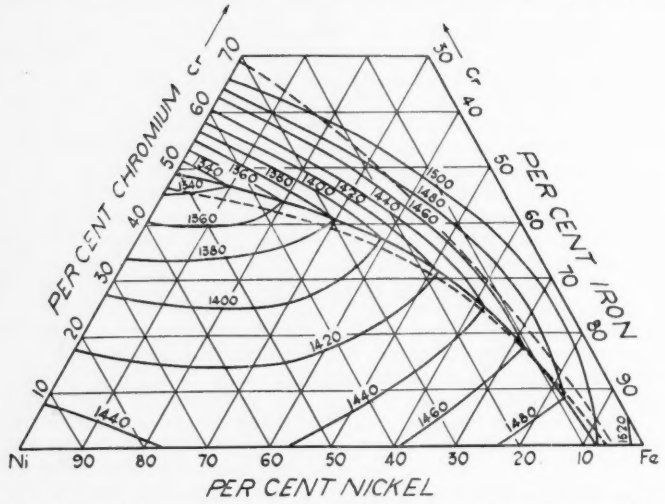

FIG. 9.—The Liquidus Surface of the Nickel-Chromium-Iron System, after Wever and Jellinghaus.

constitution on heating or cooling. Krivobok and Gensamer described a dilatometric examination of the changes taking place between 1000° and — 190° C. in alloys which are austenitic (γ phase) at high temperatures.

From the constitutional standpoint, an important work on the ternary nickel-chromium-iron alloys is that of Wever and Jellinghaus, who made thermal analyses together with some microscopical, dilatometric and X-ray studies of about two hundred alloys, including seven of the binary system nickel-iron, eighteen of the binary system chromium-iron (up to 75% of chromium), twenty-one of the binary system nickel-chromium (up to 75% of chromium), with the remainder ternary alloys the chromium contents of which lay within the limits stated above; of these ternary alloys more

than one half contained over 75% of iron, so that the iron-rich corner of the system was studied in considerable detail, the remainder of the alloys being separated by intervals of approximately 5% in composition. Their alloys were made as 50-g. melts in the high-frequency induction furnace from electrolytic iron, high-purity shot nickel and thermit chromium. The last-named material was found to contain approximately 98% of chromium, together with 0·86% of iron, 0·56% of silicon and 0·01% of aluminium. After melting in magnesia crucibles under hydrogen, the alloys were found to contain variable proportions of silicon up to 1·5%.

Wever and Jellinghaus accepted as a basis for the ternary diagram the binary diagrams of Oberhoffer and Esser for iron-chromium alloys and of Kasé for iron-nickel alloys. By means of thermal analyses these authors explored the liquidus surface and obtained the results from which Fig. 9 was drawn to represent the surface by means of isothermals. This diagram indicates that the liquidus surface consists of a steeply sloping surface falling from the chromium corner, and a more nearly horizontal surface falling slowly from the nickel-iron side. These surfaces intersect, roughly in the centre of the diagram, along a curving valley line which passes downwards from the peritectic transition point of the nickel-iron system to the eutectic point of the chromium-nickel system. This valley line is the limit on the liquidus surface of the three-phase field ($\alpha + \gamma +$ liquid) suggested by Tasaki. The other limits are also shown in Fig. 9 (although they lie below the liquidus surface) as dotted lines which join the points representing the compositions of the α phase or γ phase at the eutectic and peritectic temperatures. The curve representing the composition of the γ phase naturally lies towards the iron side of the liquidus valley line at the higher extremity and towards the nickel side of the valley line at the lower extremity (peritectic changing to eutectic reaction), and crosses it at an intermediate point near 75% iron, 15% chromium and 10% nickel at 1470° C. At this point the composition of the γ phase first separating on the solidification of liquid is identical with that of the liquid. Elsewhere on the valley line the initial stage of solidification involves the simultaneous separation of α and γ. Wever and Jellinghaus fixed the limits of this three-phase field from thermal data by classifying the cooling curves into those representing the solidification of a solid solution and those in which a temperature of secondary crystallisation was indicated.

Their cooling curves indicated approximately the temperature at which solidification ends and, in the case of the iron-rich alloys particularly, one or more arrests in the solid state. In the alloys containing iron in excess of 75% the changes in solid constitution corresponding to the γ–α transformation on cooling were also examined dilatometrically and arrests obtained at temperatures between 900° and 0° C., which gave rise on each section of constant iron content to two nearly horizontal curves

usually separated by 50–100° C., occurring at lower temperatures as the iron content of the section decreased. These points differed usually by only 3–5° C. from the thermal arrests in the solid state and defined the two-phase field at the base of the γ loop, derived from the chromium-iron system but depressed by the addition of nickel. These authors also draw attention to X-ray evidence of a tendency for compound formation, at the lower temperatures, adjacent to the composition FeCr, evidently corresponding to the "brittle constituent" described by Bain and Griffiths.

Although the investigation of Wever and Jellinghaus is fairly comprehensive their work is by no means final as (1) the purity of the alloys was not very high and rather variable, (2) the thermal data do not point directly to the form of liquidus surface shown in Fig. 10, which has been arrived at only after considerable "smoothing," (3) there has been no study of the solid constitution in alloys beyond 25% of nickel plus chromium and above this limit their diagrams rest only on heating and cooling experiments (thermal and dilatometric) and not on prolonged heat treatments, which would seem to be necessary in a system in which diffusion is so sluggish, (4) the fields immediately below the liquidus (α + liquid, γ + liquid, $\alpha + \gamma$ + liquid) have not been explored by quenching experiments.

In the present work the materials employed have been somewhat purer, and microscopical study of the alloys after annealing has defined more closely the constitution of the alloys between the liquidus temperature and 800° C. than in previous investigations. The five series of alloys studied correspond to chromium contents of 10, 20, 30, 40 and 50%, with nickel and iron contents in stages of approximately 10%. It should be remarked that none of these alloys lies at the composition of the compound mentioned above and also that no attempt has yet been made to extend the investigations to materials containing additional elements such as carbon, or to changes occurring below 800° C. The alloys with 10–30% of chromium were made from electrolytic iron, specially selected shot nickel, and a selected grade of thermit chromium containing as the main impurities 0·53% of iron and 0·2% of silicon; for the alloys containing 40 and 50% of chromium, electrolytic chromium was employed. As will be seen from the analyses given in Table III., the alloys contain varying proportions of insoluble matter, principally Cr_2O_3, up to 0·75%, and silicon, the content of which never exceeds 0·16%. Spectrographic analysis of the alloy *N40C30F30* indicated a faint trace of calcium and a very faint trace of copper, magnesium, sodium, silicon and aluminium. For the main purpose of the present investigation, to correlate the properties of the alloys at high temperatures with their structure, the content of impurities was not regarded as excessive. The alloys were prepared under hydrogen in alumina crucibles in the high-frequency induction furnace. It was found necessary to make up two batches of the ternary alloys for each

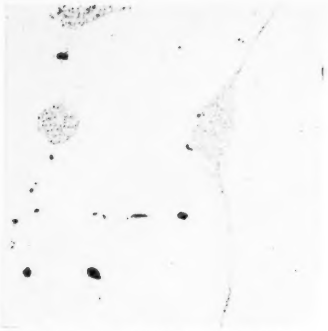

FIG. 17.—Alloy *N*70*C*30, ½ hr. 1385° C., quenched. γ + liquid. × 150.

FIG. 18.—Alloy *N*10*C*90(*B*), ½ hr. 1452° C., quenched. α + liquid. × 250.

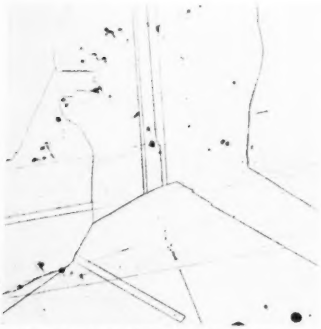

FIG. 19.—Alloy *N*60*C*40, 14 days 950° C., quenched. γ. × 150.

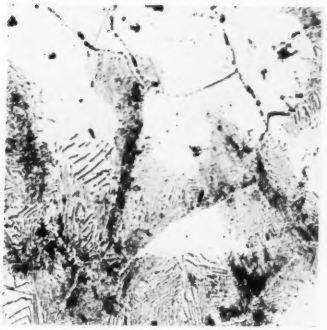

FIG. 20.—Alloy *N*60*C*40, 21 days 800° C., quenched. $\gamma + \alpha$. × 100.

FIG. 21.—Alloy *N*55*C*45, 1 day 1200° C., quenched. γ. × 50.

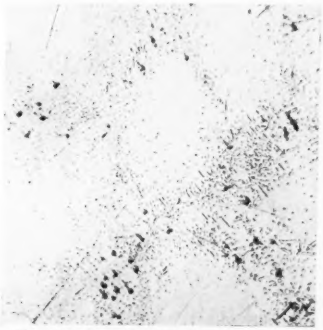

FIG. 22.—Alloy *N*55*C*45, 14 days 1100° C., quenched. $\gamma + \alpha$. × 150.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jenkins and others.*

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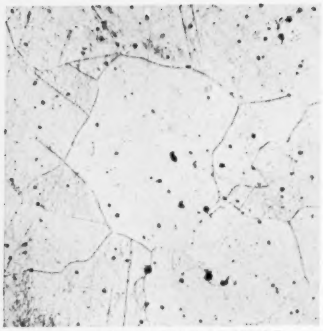

FIG. 23.—Alloy *N*53*C*47, ¾ hr. 1335° C., quenched. γ. × 50.

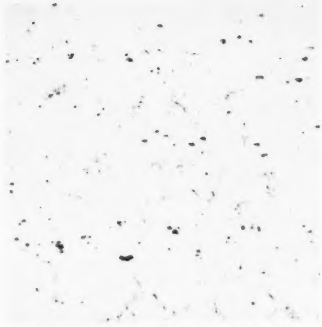

FIG. 24.—Alloy *N*53*C*47, 1 hr. 1320° C., quenched. $\gamma + \alpha$. × 50.

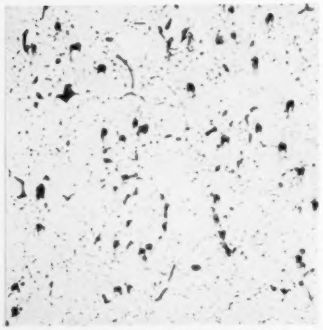

FIG. 25.—Alloy *N*53*C*47, 14 days 1100° C., quenched. $\gamma + \alpha$. × 100.

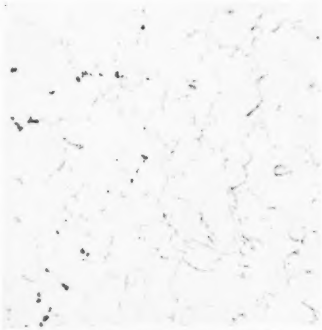

FIG. 26.—Alloy *N*51*C*49, ¾ hr. 1335° C., quenched. $\gamma + \alpha$. × 50.

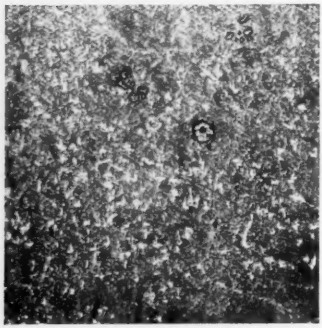

FIG. 27.—Alloy *N*30*C*70, 3 days 1300° C., quenched. $\alpha + \gamma$. × 200.

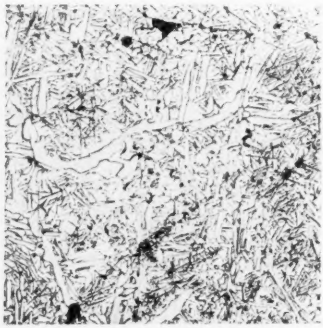

FIG. 28.—Alloy *N*25*C*75, 3 days 1200° C., quenched. $\gamma + \alpha$ with markings. × 150.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jenkins and others.*

FIG. 29.—Alloy *N*20*C*80(*A*), 3 days 1200° C., quenched. $\gamma + \alpha$ with markings. × 500.

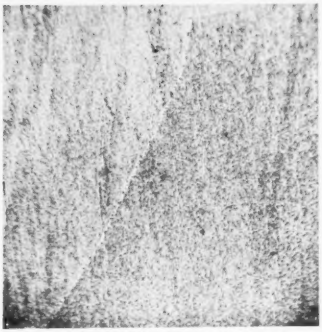

FIG. 30.—Alloy *N*10*C*90, 21 days 800° C., quenched. α + film of γ. × 500.

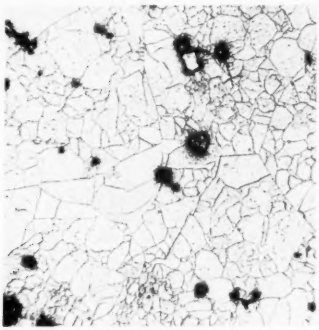

FIG. 31.—Alloy *N*25*C*75, 1 hr. 1320° C., quenched. α and Cr skulls. × 150.

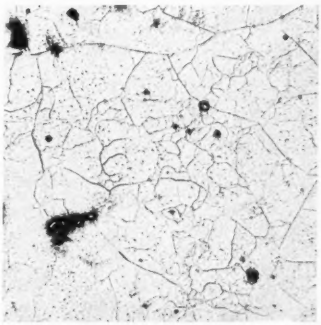

FIG. 32.—Alloy *N*20*C*80, 1 hr. 1320° C., quenched. α and Cr skulls. × 150.

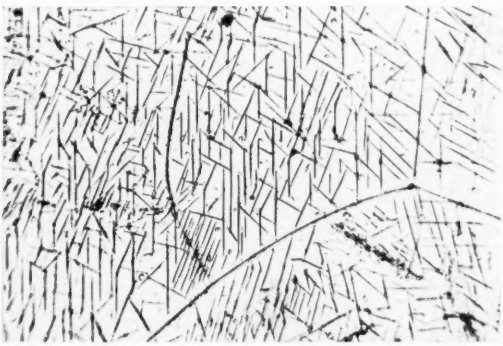

FIG. 33.—Alloy *N*15*C*85, 3 days 1200° C., quenched. α with markings. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jenkins and others.*

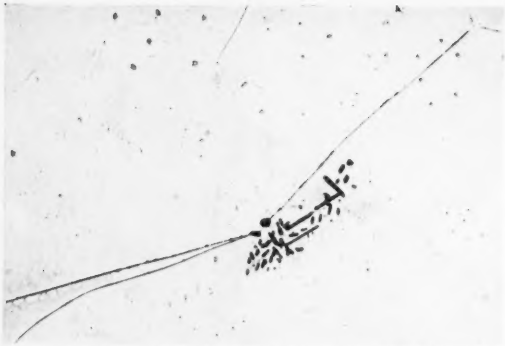

FIG. 34.—Alloy *N*10*C*90, 14 days 1100° C., quenched. Probably α with markings. × 500.

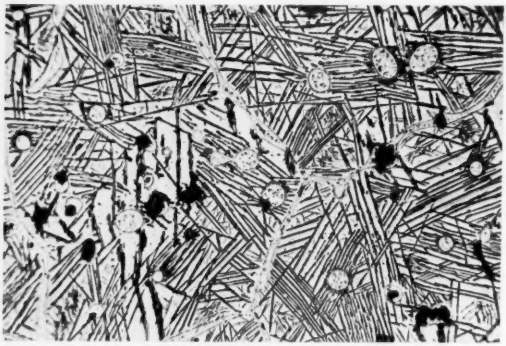

FIG. 35.—Alloy *N*20*C*80, ½ hr. 1382° C. in nitrogen and quenched. Liquid + α with markings. × 150.

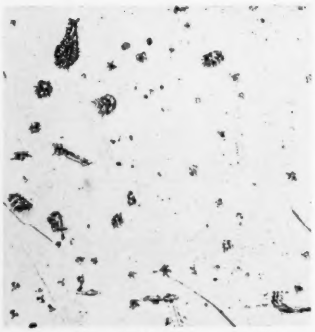

FIG. 36.—Alloy *N*50*C*20*F*30, quenched from 1359° C. γ + liquid. × 100.

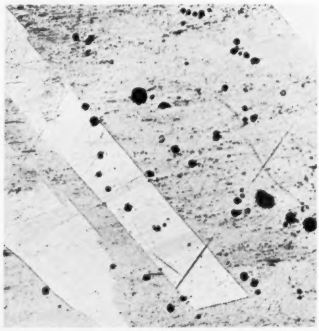

FIG. 37.—Alloy *N*50*C*20*F*30, quenched from 1352° C. γ. × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jenkins and others.*

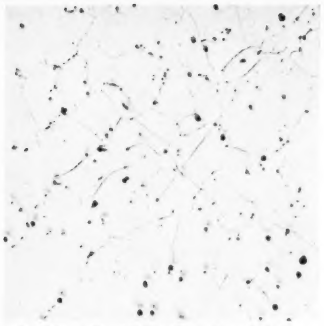

FIG. 38.—Alloy *N*50*C*20*F*30, air-cooled from 1000° C. γ. × 50.

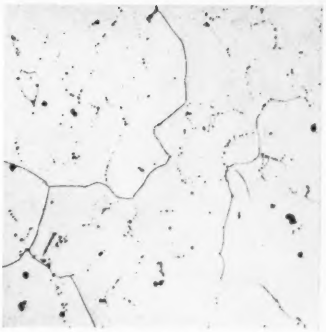

FIG. 39.—Alloy *N*30*C*30*F*40, quenched from 1200° C. γ. × 50.

FIG. 40.—Alloy *N*20*C*30*F*50, quenched from 1374° C. γ + liquid. × 100.

FIG. 41.—Alloy *N*20*C*30*F*50, quenched from 1370° C. $\alpha + \gamma$ + liquid. × 100.

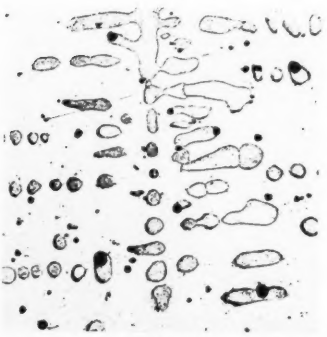

FIG. 42.—Alloy *N*20*C*30*F*50, quenched from 1368° C. $\alpha + \gamma$. × 100.

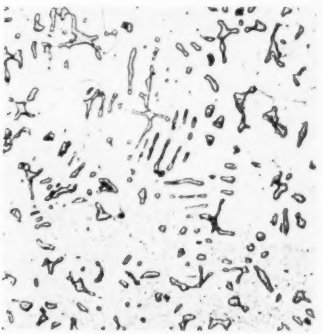

FIG. 43.—Alloy *N*20*C*30*F*50, quenched from 1200° C. $\alpha + \gamma$. × 50.

(Micrographs reduced to two-thirds linear in reproduction.)

{Jenkins and others.

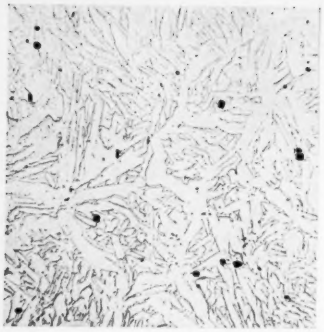

FIG. 44.—Alloy *N*10*C*30*F*60, air-cooled from 1000° C. $\alpha + \gamma$. × 50.

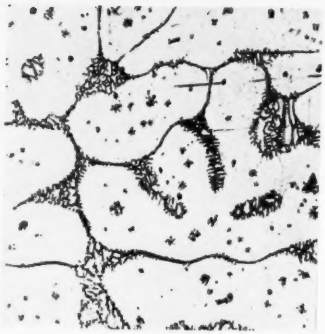

FIG. 45.—Alloy *N*40*C*40*F*20, quenched from 1352° C. γ + liquid. × 100.

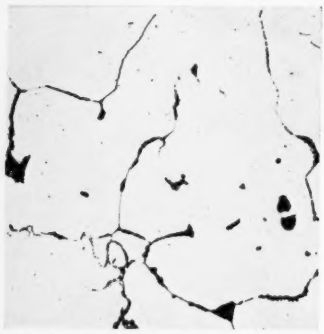

FIG. 46.—Alloy *N*30*C*40*F*30, quenched from 1352° C. γ + liquid. × 100.

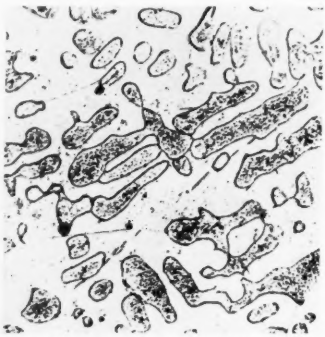

FIG. 47.—Alloy *N*30*C*40*F*30, quenched from 1349° C. $\gamma + \alpha$. × 100.

FIG. 48.—Alloy *N*30*C*40*F*30, air-cooled from 1200° C. $\alpha + \gamma$. × 50.

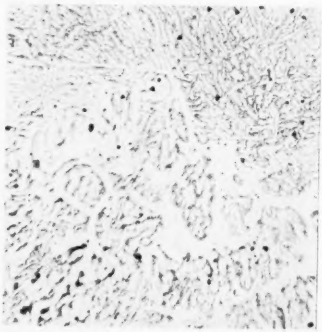

FIG. 49.—Alloy *N*20*C*40*F*40, quenched from 1200° C. $\alpha + \gamma$. × 50.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jenkins and others.*

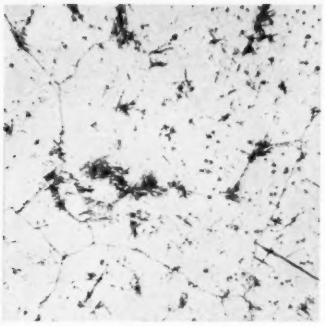

FIG. 50.—Alloy *N*10*C*40*F*50, quenched from 1200° C. $\alpha + \gamma$. × 50.

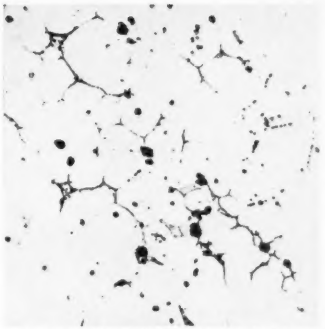

FIG. 51.—Alloy *N*40*C*50*F*10, quenched from 1314° C. α + liquid. × 100.

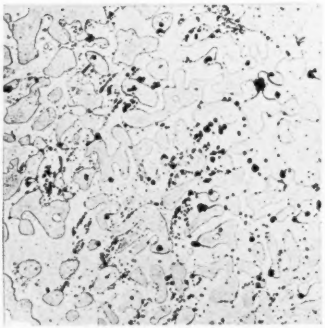

FIG. 52.—Alloy *N*40*C*50*F*10, quenched from 1304° C. $\alpha + \gamma$. × 100.

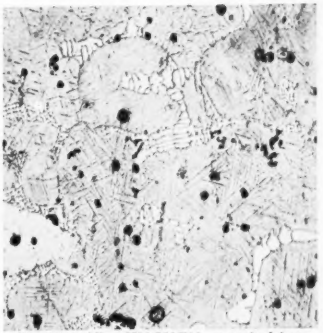

FIG. 53.—Alloy *N*30*C*50*F*20, quenched from 1355° C. α + liquid. × 100.

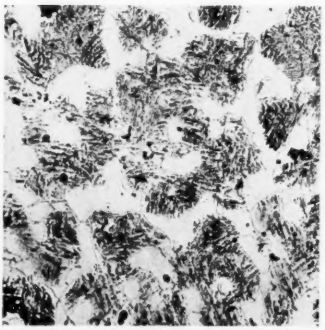

FIG. 54.—Alloy *N*30*C*50*F*20, quenched from 1347° C. $\alpha + \gamma$. × 100.

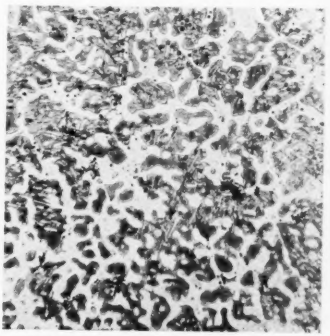

FIG. 55.—Alloy *N*30*C*50*F*20, air-cooled from 1200° C. $\alpha + \gamma$. × 50.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jenkins and others.*

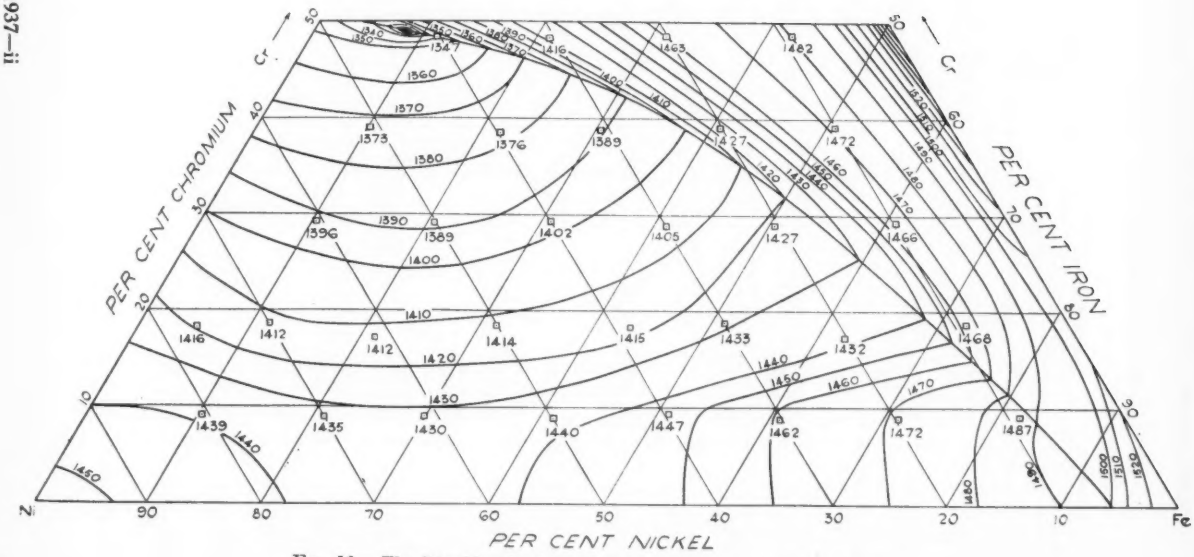

FIG. 10.—The Liquidus Surface of the Nickel-Chromium-Iron System.

TABLE III.—*Nickel-Chromium-Iron Alloys.*

Alloys and Temperatures of Thermal Arrests. ° C. (*N* = Ni; *C* = Cr; *F* = Fe.) *Cl* = cooling. *Ht* = heating. *m* = maximum. *e* = end.	Chemical Analyses. *S* = on material as used for study of solid constitution. *T* = after thermal curve determination. In. = insoluble residue.	Constitution after Heat Treatment (Summary). *M* = liquid. hr. = hour. d. = day. Temperatures in ° C.
*N*80*C*10*F*10 *Cl* 1438 *m*, 1399 *e* *Ht* 1439	*S* Ni 80·7%, Si 0·03%, Cr 9·2%, In. 0·04%, Fe 10·1%, C 0·03%	$\gamma + M$ ½ hr. 1409–1422 γ 21 d. 800; ½ hr. 1401
*N*70*C*10*F*20 *Cl* 1434 *m*, 1404 *e* *Ht* 1435	*S* Ni 70·0%, Si 0·04%, Cr 9·5%, In. 0·08%, Fe 19·8%	$\gamma + M$ ½ hr. 1402–1410 γ 21 d. 800; 3 d. 1200
*N*60*C*10*F*30 *Cl* 1426 *m*, 1398 *e* *Ht* 1433		$\gamma + M$ ½ hr. 1398 γ 21 d. 800; ½ hr. 1396
*N*50*C*10*F*40 *Cl* 1432 *m*, 1398 *e* *Ht* 1447	*S* Ni 50·9%, Si 0·03%, Cr 9·4%, In. 0·14% Fe 39·5%	$\gamma + M$ ½ hr. 1400–1405 γ 21 d. 800; 3 d. 1200
*N*40*C*10*F*50 *Cl* 1441 *m*, 1402 *e* *Ht* 1452	*S* Ni 40·7%, Si 0·02%, Cr 8·7%, In. 0·06%, Fe 50·3%	$\gamma + M$ ½ hr. 1409 γ 21 d. 800; ½ hr. 1403
*N*30*C*10*F*60 *Cl* 1452 *m*, 1407 *e* *Ht* 1471		$\gamma + M$ ½ hr. 1412 γ 21 d. 800; ½ hr. 1412
*N*20*C*10*F*70 *Cl* 1470 *m*, 1425 *e* *Ht* 1473	*S* Ni 20·1%, Si 0·02%, Cr 9·2%, In. 0·12%, Fe 70·7%	$\gamma + M$ ½ hr. 1424 γ 21 d. 800; ½ hr. 1423
*N*10*C*10*F*80 *Cl* 1483 *m*, 1442 *e*, 1429 *Ht* 1491		$\gamma + M$ ½ hr. 1445 γ 21 d. 800; ½ hr. 1439
*N*75*C*20*F*5 *Cl* 1414 *m*, 1384 *e* *Ht* 1418	*T* Ni 74·8% Cr 19·1% Fe 6·1%	
*N*70*C*20*F*10 *Cl* 1410 *m*, 1369 *e* *Ht* 1414	*T* Ni 70·0% Cr 18·9% Fe 11·1%	$\gamma + M$ ½ hr. 1366–1384 γ 21 d. 800; ½ hr. 1360
*N*60*C*20*F*20 *Cl* 1406 *m*, 1368 *e* *Ht* 1416	*T* Ni 61·4% Cr 17·5%, Fe 21·1%	$\gamma + M$ ½ hr. 1359–1365 γ 21 d. 800; ½ hr. 1355
*N*50*C*20*F*30 *Cl* 1408 *m*, 1362 *e* *Ht* 1419	*S* Ni 50·4%, Si 0·10%, Cr 18·9%, In. 0·15%, Fe 30·3%	$\gamma + M$ ½ hr. 1359–1360 γ 21 d. 800; ½ hr. 1356
*N*40*C*20*F*40 *Cl* 1415 *m*, 1380 *e* *Ht* 1415	*T* Ni 38·5%, Cr 18·5%, Fe 43·0%	$\gamma + M$ ½ hr. 1372–1385 γ 21 d. 800; ½ hr. 1368
*N*30*C*20*F*50 *Cl* 1430 *m*, 1389 *e* *Ht* 1435	*T* Ni 29·9%, Cr 19·1%, Fe 49·6% *S* 30·6%, Si 0·07%, 19·7%, In. 0·17%,	$\gamma + M$ ½ hr. 1378–1384 γ 21 d. 800; 3 d. 1200
*N*20*C*20*F*60 *Cl* 1431 *m*, 1396 *e* *Ht* 1433	*T* Ni 20·4%, Cr 17·5% Fe 62·2%	$\gamma + M$ ½ hr. 1410 γ 21 d. 800; ½ hr. 1407
*N*10*C*20*F*70 *Cl* 1465 *m*, 1426 *e*, 1364 *Ht* 1470	*T* Ni 9·0%, Cr 19·0%, Fe 72·5% *S* 10·6%, Si 0·05%, 19·6%, In. 0·10%, 69·8%	$\alpha + M$ ½ hr. 1423 α ½ hr. 1407–1422 γ 21 d. 800; 3 d. 1200

TABLE III. (*continued*).

Alloys and Temperatures of Thermal Arrests. ° C. (*N* = Ni; *C* = Cr; *F* = Fe.) *Cl* = cooling. *Ht* = heating. *m* = maximum. *e* = end.	Chemical Analyses. *S* = on material as used for study of solid constitution. *T* = after thermal curve determination. In. = insoluble residue.	Constitution after Heat Treatment (Summary). *M* = liquid. hr. = hour. d. = day. Temperatures in ° C.
*N*60*C*30*F*10 *Cl* 1395 *m*, 1349 *e* *Ht* 1396	*S* Ni 59·5%, Si 0·11%, Cr 29·5%, In. 0·10%, Fe 10·3%	$\gamma + M$ ½ hr. 1358 γ 21 d. 800; ½ hr. 1356
*N*50*C*30*F*20 *Cl* 1390 *m*, 1336 *e* *Ht* 1388		$\gamma + M$ ½ hr. 1356–1358 γ 21 d. 800; ½ hr. 1355
*N*40*C*30*F*30 *Cl* 1399 *m*, 1363 *e* *Ht* 1402	*S* Ni 40·1%, Si 0·10%, Cr 29·4%, In. 0·15%, Fe 30·1%	$\gamma + M$ ½ hr. 1354–1358 γ 21 d. 800; 3 d. 1200
*N*30*C*30*F*40 *Cl* 1406 *m*, 1354 *e* *Ht* 1404	*S* Ni 30·4%, Si 0·08%, Cr 28·2%, In. 0·27%, Fe 40·7%, C 0·02%	$\gamma + M$ ½ hr. 1358–1372 γ 21 d. 800; 3 d. 1200
*N*20*C*30*F*50 *Cl* 1408 *m*, 1370 *e* *Ht* 1446	*S* Ni 20·3%, Si 0·08%, Cr 29·0%, In. 0·26%, Fe 50·3%, C 0·14% *	$\gamma + M$ ½ hr. 1374 $\alpha + \gamma + M$ ½ hr. 1370–1372 $\alpha + \gamma$ 21 d. 800; ½ hr. 1368
*N*10*C*30*F*60 *Cl* 1466 *m*, 1404 *e* *Ht* 1466	*S* Ni 10·4%, Si 0·08%, Cr 29·3%, In. 0·20%, Fe 60·1%	$\alpha + M$ ½ hr. 1430–1434 α ½ hr. 1423–1424 $\alpha + \gamma$ 21 d. 800; 3 d. 1200
*N*50*C*40*F*10 *Cl* 1364 *m*, 1294 *e* *Ht* 1382	*T* Ni 50·5%, Cr 39·5%, Fe 9·9%, Si 0·12% *S* 50·0%, In. 0·24%, 39·3%, C 0·03%, 10·3%, 0·08%	$\gamma + M$ ½ hr. 1352 γ ½ hr. 1342–1347 $\gamma + \alpha$ 21 d. 800; 3 d. 1200
*N*40*C*40*F*20 *Cl* 1374 *m*, 1339 *e* *Ht* 1378	*T* Ni 39·9%, Cr 39·0%	$\gamma + M$ ½ hr. 1352–1359 γ ½ hr. 1342–1347 $\gamma + \alpha$ 21 d. 800; 3 d. 1200
*N*30*C*40*F*30 *Cl* 1386 *m*, 1348 *e* *Ht* 1388	*S* Ni 29·8%, Si 0·14%, Cr 38·3%, In. 0·70%, Fe 30·1%	$\gamma + M$ ½ hr. 1352–1384 $\gamma + \alpha$ 21 d. 800; ½ hr. 1349
*N*20*C*40*F*40 *Cl* 1429 *m*, 1363 *e* *Ht* 1423		$\gamma + \alpha$ 21 d. 800; ½ hr. 1368
*N*10*C*40*F*50 *Cl* 1476 *m*, 1413 *e*, 1352 *Ht* 1468, 1381	*S* Ni 10·1%, Si 0·11%, Cr 38·2%, In. 0·35%, Fe 50·7%, C 0·02%	$\alpha + M$ ½ hr. 1434 α ½ hr. 1423–1430 $\alpha + \gamma$ 21 d. 800; 3 d. 1200
*N*40*C*50*F*10 *Cl* 1341 *m*, 1304 *e* *Ht* 1353	*T* Ni 40·1%, Cr 48·5%, Fe 10·0% *S* 38·4%, Si 0·16%, 49·8%, In. 0·34%, 10·6%	$\alpha + M$ ½ hr. 1314 α ½ hr. 1310 $\alpha + \gamma$ 21 d. 800; ½ hr. 1304
*N*30*C*50*F*20 *Cl* 1413 *m*, 1348 *Ht* 1419, 1361	*T* Ni 30·3%, Cr 48·2%, Fe 20·4% *S* 29·6%, Si 0·10%, 47·1%, In. 0·56%, 20·4%	$\alpha + M$ ½ hr. 1355 $\alpha + \gamma$ 21 d. 800; ½ hr. 1347
*N*20*C*50*F*30 *Cl* 1463 *m*, 1363 *e*	*S* Ni 21·5%, Si 0·09%, Cr 49·1%, In. 0·75%, Fe 30·4%, C 0·04%	$\alpha + M$ ½ hr. 1409–1423 $\alpha + \gamma$ 21 d. 800; 3 d. 1200
*N*10*C*50*F*40 *Cl* 1482 *m*, 1438 *e* *Ht* 1481	*S* Ni 8·9%, Si 0·14%, Cr 48·3%, In. 0·62%, Fe 41·7%	$\alpha + M$ ½ hr. 1434–1436 α ½ hr. 1424 $\alpha + \gamma$ 21 d. 800; 3 d. 1200

* *See* next page, line 8.

composition; 50-g. ingots for thermal analysis and 50-g. ingots for solidus determinations and for the study of solid constitution. These are referred to in Table III. as *T* and *S* respectively.

The values for the liquidus arrests on heating and cooling are given in Table III. and plotted in Fig. 10. The tabulated values are the maxima of arrests on heating and recalescence temperatures on cooling; these are usually in close or fair agreement, but in one instance, *N*20*C*30*F*50, they differ by 38° C. This alloy was found on analysis to be contaminated with 0·14% of carbon. The values given in Fig. 10 are averaged, and the liquidus surface is indicated by means of isothermal contours at 10° C. intervals, which have been smoothed to approximately ± 3° C. The accuracy of the determinations is probably not greater than ± 5° C.

The liquidus surface now put forward differs from that of Wever and Jellinghaus mainly in that the valley line connecting the eutectic point of the nickel-chromium system with the end of the peritectic horizontal of the system iron-nickel is now shown not to rise smoothly from the eutectic temperature, 1342° C., to the peritectic temperature, 1499° C., but at first to fall and only later to rise. The point of minimum temperature represents an alloy which solidifies at constant temperature, just as does the binary eutectic, and may be referred to as a depressed binary eutectic point. It is suggested that this point lies near the composition 49% chromium, 8% iron, 43% nickel, with a melting point below 1300° C., but the main evidence for the existence of this is derived from the solidus determinations (*see* below). The surface differs in some respects from that previously published [28] with an account of the mechanical properties of nickel-chromium-iron alloys. The alterations consist of the insertion of the valley line and adjustments for chemical analysis and in the interpretation of thermal data.

The results of quenching experiments to determine the solidus temperatures are given in Table III. and plotted in Fig. 11. In Table III. are given the extreme ranges of temperature at which each type of microstructure was found, as was done in Table II. Each temperature stated in Fig. 11 is the mean of the temperatures at which liquid was first found and last absent in the quenching experiments, except the value for alloy *N*20*C*50*F*30, which is based on thermal curve data. The solidus surface is represented by isothermal contours at 10° C. intervals. This surface consists of three parts, namely (1) the interface between the γ + liquid and γ fields, corresponding to nickel-rich alloys, (2) the interface between the α + liquid and α fields, corresponding to alloys of low nickel content, and (3) the interface between an $\alpha + \gamma$ + liquid field and the $\alpha + \gamma$ field, underlying the valley line in the liquid surface. This third surface is a "ruled surface," *i.e.*, horizontal sections are straight lines, but at the depressed eutectic point it narrows to a point, which lies at a temperature below 1312° C., the solidus temperature for the alloy *N*40*C*50*F*10, and probably below 1300° C. Between the boundaries

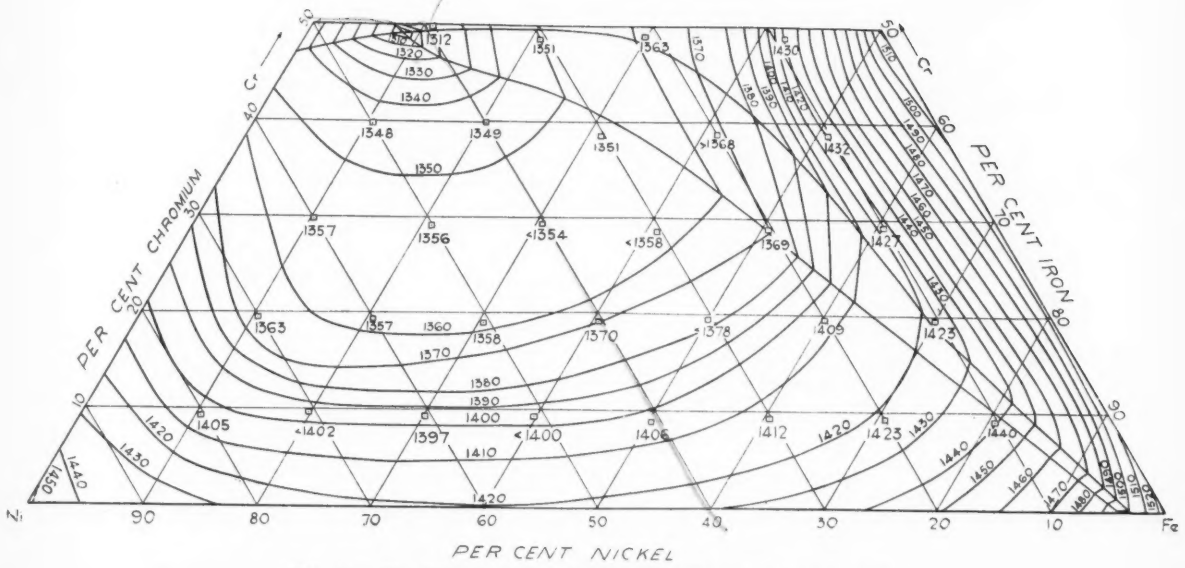

FIG. 11.—The Solidus Surface of the Nickel-Chromium-Iron System.

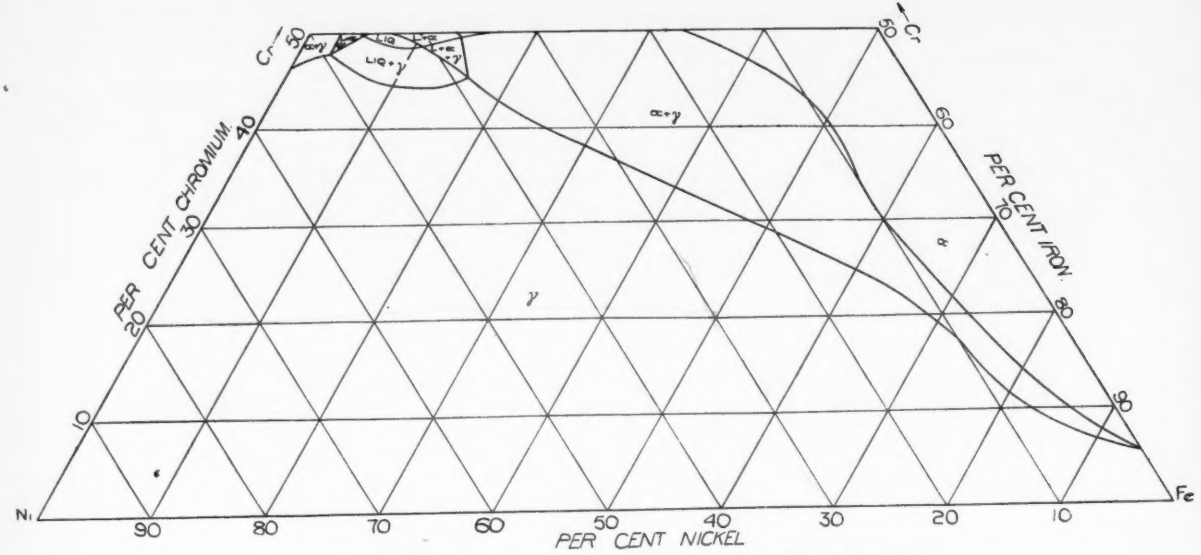

FIG. 12.—The Constitution of the Nickel-Chromium-Iron System at 1330° C.

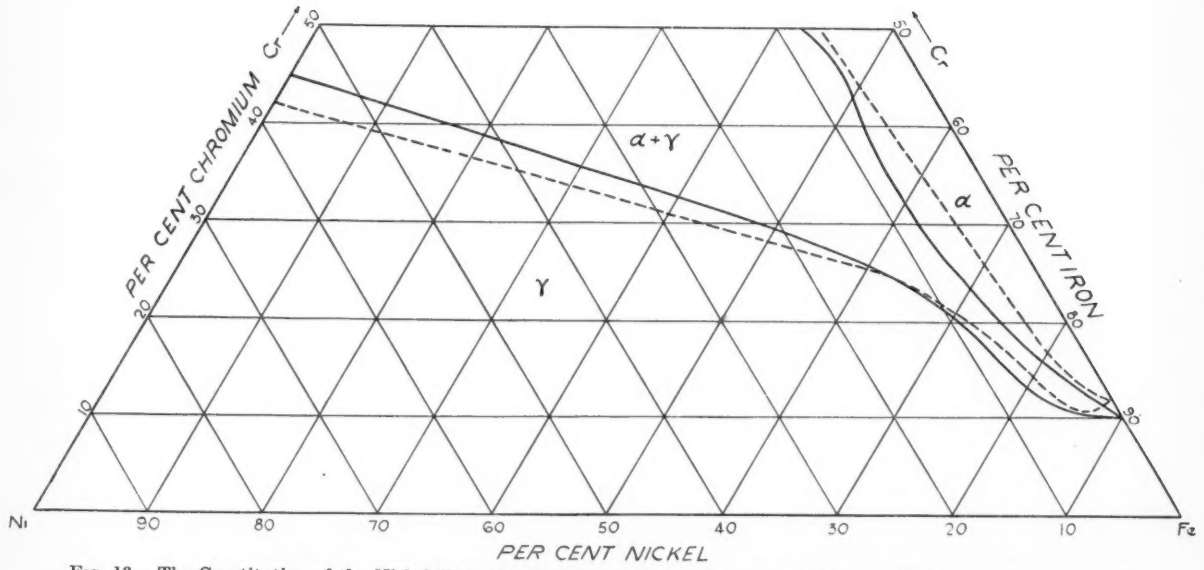

FIG. 13.—The Constitution of the Nickel-Chromium-Iron System at 1200° and at 1000° C. (1200° C., full line; 1000° C., dashed line).

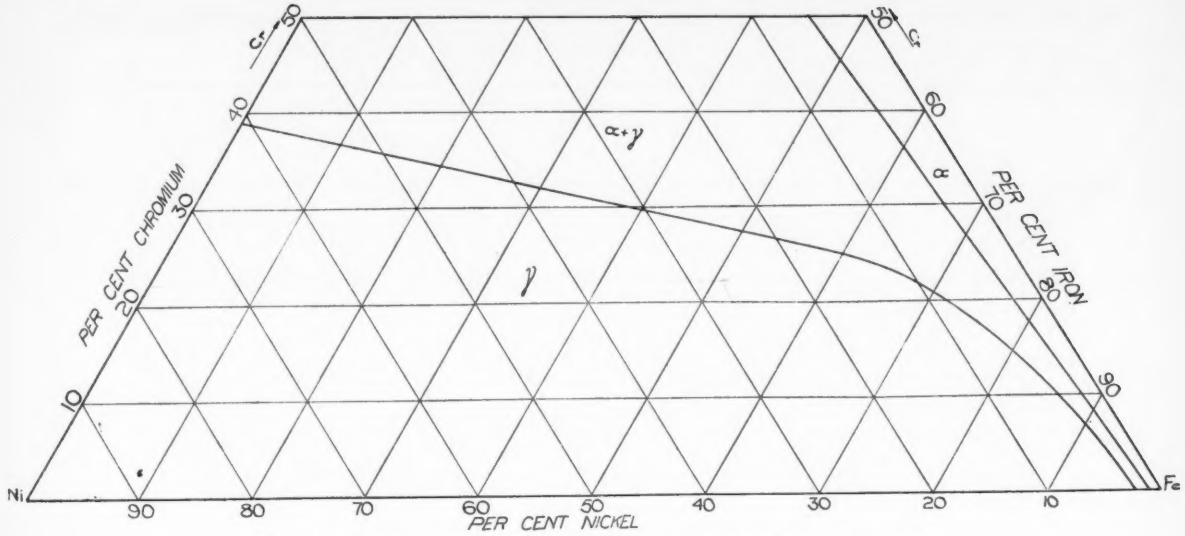

FIG. 14.—The Constitution of the Nickel-Chromium-Iron System at 800° C.

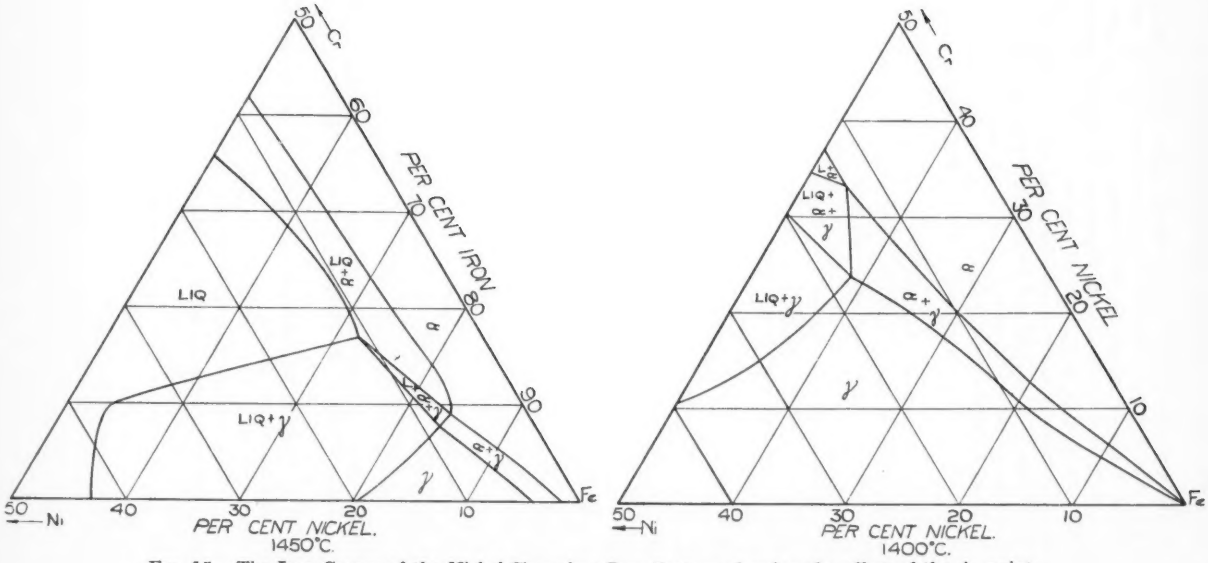

FIG. 15.—The Iron Corner of the Nickel-Chromium-Iron System, showing the effect of the A_4 point.

of this part of the solidus surface and the liquidus valley line lie the interfaces of the $\alpha + \gamma +$ liquid field with the $\alpha +$ liquid and the $\gamma +$ liquid fields which are again ruled surfaces. Some information relating to these surfaces has been found in the solidus quenching experiments, *see* Table III., but they have not been studied in detail, as they have no great practical significance. Figs. 36, 37, 40, 41, 42, 45, 46, 47, 51, 52, 53 and 54 illustrate the microstructures,

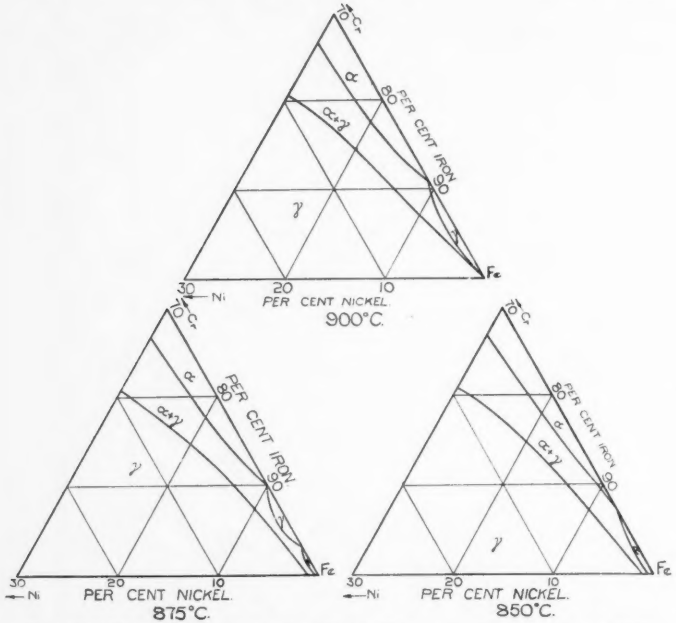

FIG. 16.—The Iron Corner of the Nickel-Chromium-Iron System at 900°, 875° and 850° C., showing the effect of the A_3 point.

as revealed by etching in Vilella's reagent,[27] of alloys quenched from near solidus temperatures.

The three annealing treatments which were carried out at 1200°, 1000° and 800° C., when taken in conjunction with the results of short-time treatments near the solidus, indicate the solid constitution of the alloys. The results are set out in Table III. and are represented graphically in Figs. 12, 13 and 14, which show the constitution at 1330° C. (between the nickel-chromium eutectic and the depressed eutectic), 1200° and 1000° C., and 800° C. The constitution of the iron-rich alloys is indicated also by additional

sections at 1450° and 1400° C. (at the A_4 point of iron), 900° C. (at the A_3 point of iron), 875°, 850° and 825° C., *see* Figs. 15 and 16. The microstructures of typical alloys are reproduced in Figs. 38, 39, 43, 44, 48, 49, 50 and 55.

It will be seen from the diagrams that in the alloys containing up to 50% of iron, the solubility of chromium in the γ phase decreases with fall of temperature; except in the alloys containing least iron, the decrease is mainly confined to the temperature range between the solidus and 1200° C. The solubility of nickel in the α phase decreases with fall of temperature in alloys of all iron contents up to 90%.

In the iron corner the three-phase $\alpha + \gamma +$ liquid field narrows down with increasing iron content until it coincides with the peritectic line of the iron-nickel system, and the underlying $\alpha + \gamma$ field joins on to the $\alpha + \gamma$ field of the iron-nickel system, which, however, closes with decrease of temperature, terminating in a point at 1400° C. Below this temperature the $\alpha + \gamma$ field continues to the chromium side of the iron corner, terminating at the boundary line of the iron-chromium γ loop. At 900° C. (A_3) the $\alpha + \gamma$ field of the nickel-iron system reappears, and over a range of temperatures down to 850° C. this field co-exists with the γ loop of the chromium-iron system, so that in this range the ternary $\alpha + \gamma$ field joins both binary systems near the iron corner. Below the bottom of the chromium-iron γ loop at 850° C. the $\alpha + \gamma$ field of the ternary system terminates at the $\alpha + \gamma$ region of the binary nickel-iron system. In this corner of the system little detailed evidence is at present available, but the examination of a new series of alloys is under consideration. Heat treatment at various temperatures will be given to define rather closely the areas occupied by the phase fields indicated schematically in Figs. 15 and 16.

The authors wish to acknowledge their indebtedness to the late Dr. W. Rosenhain for suggestions in the initial stages of the work and to Dr. C. H. Desch, F.R.S., Superintendent of the Metallurgy Department of the National Physical Laboratory, for his interest during the later stages. They are also grateful to members of the staff of the Metallurgy Department for assistance and for chemical analyses, particularly Mr. P. Ward and Mr. N. P. Tucker, and to the late Mr. H. Grant for very considerable assistance in the experimental work.

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CORRESPONDENCE.

Professor Dr., Dr.-Ing. E.h. E. JÄNECKE (Heidelberg, Germany) wrote that the authors' Figs. 10 and 11, relating to the liquidus and solidus surfaces of the nickel-chromium-iron system, differed from the diagram of Wever and Jellinghaus not only in small temperature differences but more especially in the fact that the eutectic temperature of the nickel-chromium system decreased in the ternary alloys, so that the compositions of liquid in equilibrium with α and γ solid solutions ($\alpha + \gamma +$ liquid) were now indicated as lying on a curve with a minimum. The authors' opinion that

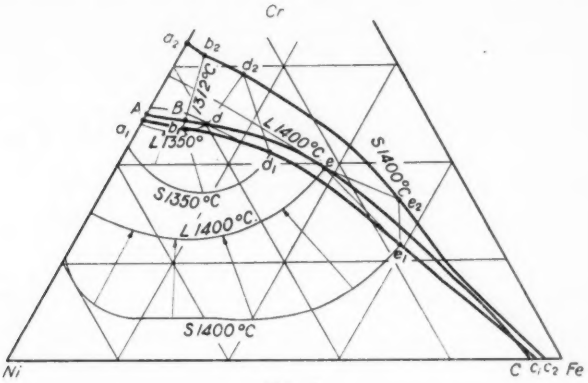


FIG. A.

solid solution of the same composition as the liquid formed at the minimum temperature was erroneous. The ruled surface which defined the conjugate α and γ solid solutions did not narrow to a point at the depressed eutectic, as shown in the authors' Fig. 11 and stated on the previous page. The true behaviour was indicated in Fig. A. At the lowest point B of the eutectic-peritectic curve $ABdeC$ the phases in equilibrium were the liquid B and the solid solutions b_1 on the γ-iron side and b_2 on the α-iron side, the points b_1, B and b_2 lying on a straight line in the diagram.

In Fig. A the solidus and liquidus curves were shown for temperatures of 1350° and 1400° C. and the supposed relations between liquid and solid phases at these temperatures were indicated. The liquids d and e were in equilibrium at 1350° and 1400° C. respectively with the solid phases d_1, d_2 and e_1, e_2.

AUTHORS' REPLY.

The AUTHORS wrote in reply that they greatly appreciated Professor Jänecke's contribution regarding the depressed eutectic point, and had already made suggestions to the Committee responsible that further work in this area be undertaken. They noted that Professor Jänecke agreed in Fig. A that the eutectic could be depressed as suggested in the paper.

The solid solubility limits put forward by Professor Jänecke (in lines a_1c_1 and a_2c_2) might perhaps be of more frequent occurrence in ternary systems than that suggested by the authors for this particular system, but both forms were in agreement with Willard Gibbs' general statement [1] that in a ternary system where three phases co-existed in equilibrium at a constant pressure "the temperature is in general a maximum or minimum . . . when the composition of one of the phases is such as can be produced by combining the other two."

The relation between the phases at 1400° C. had already been indicated in Fig. 15, and most of the information in Fig. A was already given in Figs. 10 and 11. These two figures enabled the constitution above the solidus temperatures to be derived.

[1] J. Willard Gibbs, *Scientific Papers*, 1906, vol. 1, p. 360.

A NEW METHOD FOR JUDGING THE BEHAVIOUR OF IRON ORES DURING REDUCTION.[1]

By Dipl.-Ing., Dr.phil. N. J. KLÄRDING (Dortmund, Germany).

(Fig. 1 = Plate XXV.)

SUMMARY.

After a brief reference to the reactions occurring during the reduction of iron oxide by carbon monoxide and a method and apparatus for investigating them, reduction curves for pure Fe_2O_3 obtained by Schenck and Dingmann are presented, and the influence of the temperature on the conversion of carbon monoxide into carbon dioxide is indicated. The phases formed in the iron-oxygen system as a result of these reactions are then enumerated. Finally, isothermal reduction curves for ores from Rio Tinto, Newfoundland and Lucainena (Spain) are presented and discussed.

The application of the principles of physical chemistry, especially of equilibria in metallurgical processes, has proved to be very valuable in so far as these principles eliminate the necessity of accumulating a large amount of practical experience, and has laid the foundation for a corresponding development of metallurgical processes.

At any definite temperature a reversible chemical reaction attains a definite equilibrium for which the equilibrium constant can be calculated thermodynamically.

The reactions which take place on reducing iron oxides, namely:

$Fe_2O_3 + 3CO = 2Fe + 3CO_2$, or $Fe_2O_3 + 3H_2 = 2Fe + 3H_2O$.

$Fe_3O_4 + 4CO = 3Fe + 4CO_2$, and

$FeO + CO = Fe + CO_2$,

cannot simply be determined theoretically, which implies that the quantity of carbon monoxide cannot be calculated beforehand.

Experiments have shown that on reducing pure iron oxide intermediate products are formed, which are characterised by a definite oxygen pressure or by a characteristic CO/CO_2 ratio:

$$2CO + O_2 = 2CO_2$$

$$K_p = \frac{p^2_{CO} \cdot p_{O_2}}{p^2_{CO_2}}; \qquad p_{O_2} = K_p \cdot \frac{p^2_{CO_2}}{p^2_{CO}}.$$

The iron oxide to be investigated is treated successively with measured quantities of carbon monoxide; the oxide is reduced,

[1] Received June 28, 1937.

and reduction curves are obtained by plotting the values of the compositions of the gaseous phases against the oxygen contents of the partially reduced oxides with which the gases are in equilibrium.

The apparatus used is shown in Fig. 1. It consists of electrically-heated reaction tubes, each being connected to a mercury manometer. Each evacuated reaction tube is filled with carbon monoxide from a gauged vessel to which a manometer is connected. The resulting difference of pressure before and after filling the tube provides an easy means of calculating the quantity of carbon monoxide added.

Fig. 2 represents the reduction curves obtained for pure iron oxide (Fe_2O_3) by R. Schenck and Th. Dingmann.[1] According to

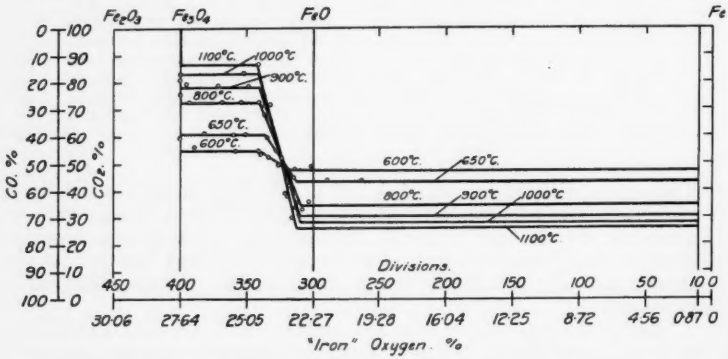


FIG. 2.—Reduction Curves for Pure Iron Oxide at Various Temperatures.

the formula $Fe_2O_3 + 3CO = 2Fe + 3CO_2$, 1 g. of Fe_2O_3 needs 0·5108 g. of carbon monoxide for it to be reduced to an oxygen content of 0·87%.

Since the reduction passes through various intermediate stages and the equilibrium ratio CO/CO_2 moves in the direction of smaller CO_2 values, more carbon monoxide is needed to effect the reduction.

According to Fig. 2 the conversion of CO into CO_2 likewise becomes less with rise of temperature; the consumption of CO is therefore greater. The quantities of carbon monoxide necessary to reduce 1 g. of Fe_2O_3 to an oxygen content of 0·87%, calculated from the equilibrium curves for various temperatures, are plotted against the temperatures in Fig. 3.

Assuming a linear curve, and applying the phase rule, $P + F = n + 2$, of Willard Gibbs to the system iron-oxygen, the number of phases formed as a consequence of the reaction can be deter-

[1] *Zeitschrift für anorganische und allgemeine Chemie*, 1927, vol. 166, p. 113.

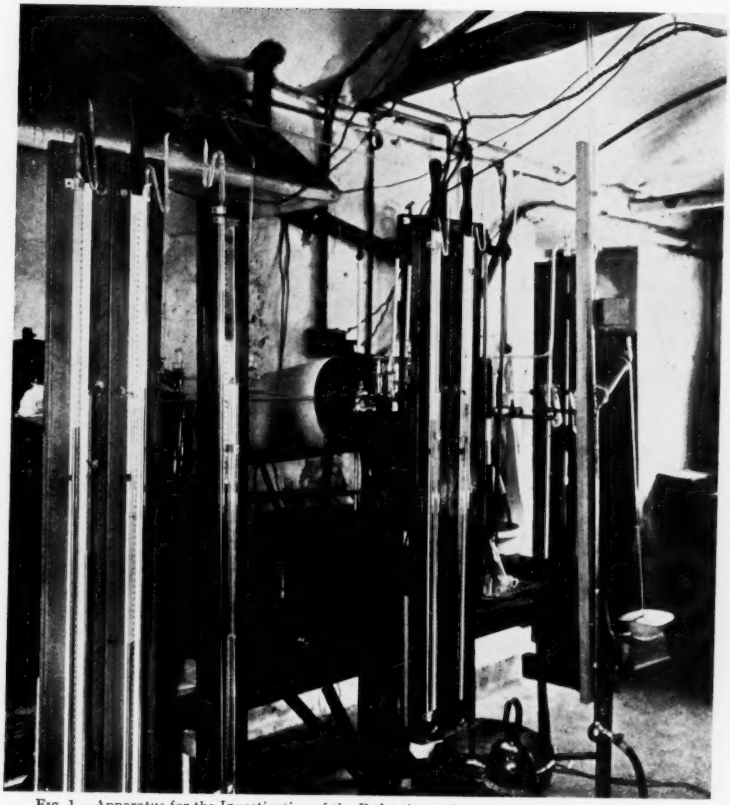


FIG. 1.—Apparatus for the Investigation of the Reduction of Iron Oxide by Carbon Monoxide.

mined. Fe_2O_3 is reduced to Fe_3O_4 when the carbon monoxide is completely converted into CO_2. This system has two components ($n = 2$), iron and oxygen, and one degree of freedom

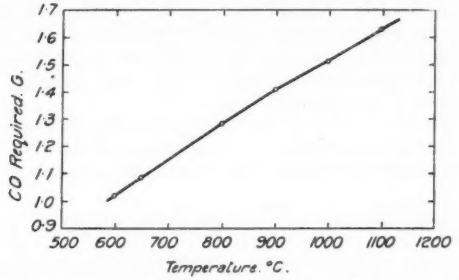


FIG. 3.—Theoretical Quantity of CO necessary at Various Temperatures to Reduce 1 g. of Fe_2O_3.

($F = 1$; the pressure or temperature may be varied independently). Along the horizontal portion of the curve at 100% CO_2, Fe_2O_3 and Fe_3O_4 are two co-existing solid phases.

The horizontal portion of the curve at the lower percentage

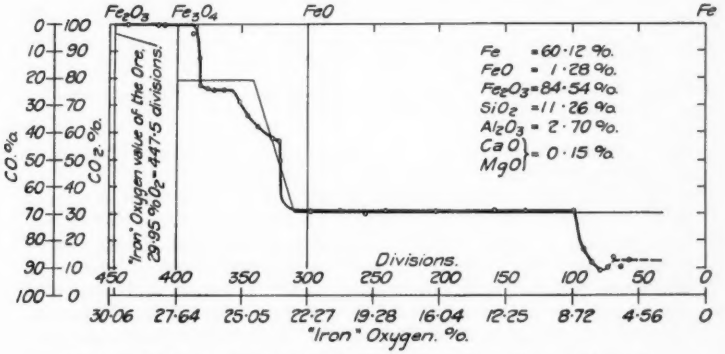


FIG. 4.—Reduction Curve of Rio Tinto Iron Ore. Temperature of reduction, 900° C.

of CO_2 signifies the reduction of Fe_3O_4 to wüstite. Directly all the Fe_3O_4 is reduced to wüstite—a solid solution of Fe_3O_4 in FeO—the curve slants down to the third horizontal portion. Along the second horizontal portion, again, there is a univariant system, in which the two phases Fe_3O_4 and wüstite co-exist. Along the

sloping portion of the curve the system is bivariant, that is, the pressure or temperature and concentration may be varied independently. The solid phase is wüstite. According to the curves in Fig. 2, there are two forms of wüstite, one rich in Fe_3O_4 at the beginning of the slanting portion of the curve, and one poor in Fe_3O_4 at the transition to the third horizontal portion of the curve. Along the third horizontal portion of the curve the two co-existing phases are wüstite poor in Fe_3O_4 and a solid solution of oxygen in metallic iron ("oxy-ferrite").

The compositions of the phases are deduced from the beginnings and end-points of the sections of the curves. The differences in the heats of formation of various iron oxides are insignificant so far as

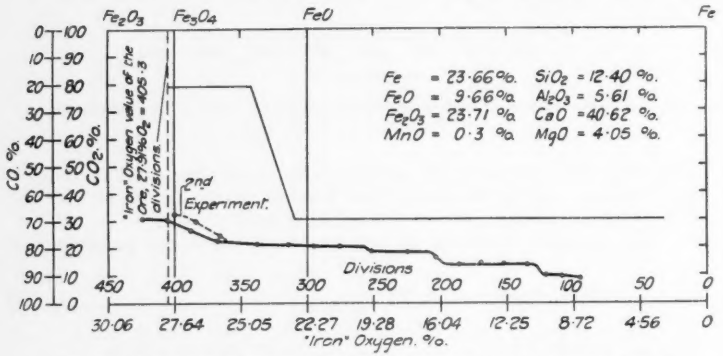


FIG. 5.—Reduction Curve of Newfoundland Iron Ore. Temperature of reduction, 900° C.

the reduction is concerned; the CO/CO_2 ratio in the gas phase over the oxide, however, is of the greatest importance.

The isothermal reduction curves at 900° C. for an iron ore from Rio Tinto are shown in Fig. 4, those for an iron ore from Newfoundland in Fig. 5, and those for spathic iron ore from Lucainena in Spain in Fig. 6. The amounts of carbon monoxide necessary to effect the reduction vary according to the amounts and nature of the impurities in the ores. These reduction curves enable one to form a clear conception of the state of affairs. The behaviour of a series of iron ores during reduction has been investigated by the author.[1]

The slags formed through the lower oxides of iron combining with other oxides, such as MgO, CaO, Al_2O_3, SiO_2, MnO, &c., can be deduced from the diagrams. The normal reduction is disturbed if these latter oxides and the iron oxides form chemical compounds or solid solutions. Furthermore, these foreign oxides may react

[1] J. Klärding, *Archiv für das Eisenhüttenwesen*, 1931–32, vol. 5, p. 129.

with each other, thereby eliminating their disturbing effect upon the various iron oxides present.[1] Thus, for example, MnO and SiO_2 react to form the compound $2MnO{\cdot}SiO_2$, so preventing MnO from forming a solid solution with Fe_3O_4.

Other investigations have shown that the ease with which the various iron ores can be reduced also depends upon the distribution of the iron oxides and foreign oxides in the ore. In cases where the iron oxide or the other oxides form clusters the reduction curve resembles that for pure iron oxide; the reduction is thus effected under more favourable conditions.

According to all the diagrams, metallic iron appears for the first time at the beginning of the third horizontal, which for a temperature

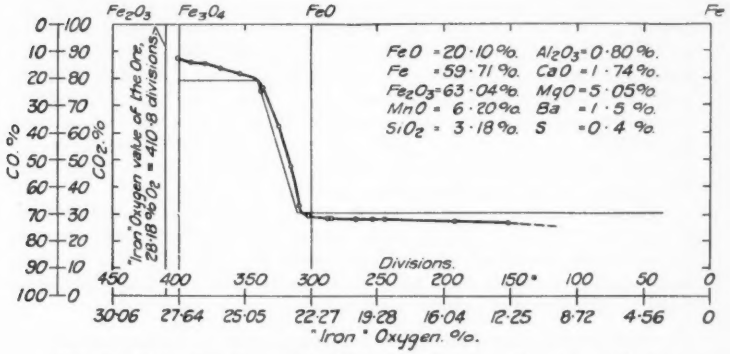


FIG. 6.—Reduction Curve of Spathic Iron Ore from Lucainena, Spain. Temperature of reduction, 900° C.

of 900° lies at approximately 30% CO_2; at the end of this horizontal the whole of the oxide has been reduced to metallic iron. The length of this horizontal portion of the reduction curve of an iron ore, which partly resembles that of pure iron oxide, can be regarded as a criterion for that portion of the iron oxide in the ore under investigation which normally becomes reduced. Putting the length of this third horizontal line in the curve for pure iron oxide equal to 100, then the percentage of reducible oxide in an ore is given by the length of the third horizontal of the reduction curve of the ore, which is co-linear with the third horizontal of the pure iron oxide. The remainder of the iron oxide represents that portion which is slagged. From the diagram the absolute quantity of slag can be deduced only when the iron oxide and the other oxides present are thoroughly intermixed. A comparison of the curves for the natural ore and for the same ore after being melted before reduction clearly shows the

[1] J. Klärding, *Archiv für das Eisenhüttenwesen*, 1934–35, vol. 8, pp. 277, 325.

degree of distribution of the iron oxide and the other components. Earlier researches by various investigators on the reducibility of iron ores with coal gas could not explain the behaviour of the iron ores on being reduced satisfactorily, because the ores after reduction always retained a definite amount of oxygen. Investigations carried out by the author on various iron ores have explained this behaviour.

The comparison of the characteristic reduction curves of different ores thus enables one to deduce clearly how the chemical composition of the gas phase depends upon the "iron" oxygen content of the solid phase. Reduction is only effected then when the CO_2 content of the gas phase is less than that given by the curve. With a gas of definite CO/CO_2 ratio, ores of different chemical compositions cannot be reduced to the same extent. So, for example, the Rio Tinto iron ore (Fig. 4) is reduced by a gas mixture containing about 30% of CO_2 and 70% of CO ($CO/CO_2 = 2{\cdot}33 : 1$) only to an oxygen content of 8%. The Newfoundland ore (Fig. 5) reacts only to a very small extent with a gas of the above composition, as is indicated by the point of intersection of the horizontal at 30% CO_2 with the reduction curve of this ore, whereas the Lucainena ore (Fig. 6) is reduced by the gas only to an extent of 22·27% of oxygen, and pure iron oxide is reduced very nearly to the pure metal. A series of these curves has been given by the author in the paper mentioned above.[1]

These reduction curves are of special interest for judging the behaviour of the reducing gases in smelting processes, also the direct reduction in the shaft of the blast-furnace, and, furthermore, for interpreting metallurgical processes where different materials are used for the furnace lining.

[1] The reduction curves of various iron ores show that one cannot generally compare the reduction of pure iron oxide with the reduction of ores. The behaviour of an ore on being reduced must be determined by experiment and cannot be calculated beforehand by thermochemical data.

HOT METAL PRACTICE IN FIVE MELTING SHOPS ON THE NORTH-EAST COAST.*

By W. GEARY (Middlesbrough).

(Figs. 1 to 20 = Plates XXVI. to XXXII.)
(Table XX. = Plate XXXIII.)

Synopsis.

Attention has recently been called to the hot metal practice of the North-East Coast, of which no recent account has been published. This paper describes the methods in present use by reference to the construction and operating of five plants. Each plant is separately described and completely discussed. The history of each is briefly mentioned and its subsequent development sketched. The plant layouts are described and adequately illustrated. The constructional details of mixers and varying designs of steel furnaces are mentioned and illustrated. The furnaces described vary from 55 tons to 250 tons capacity. Steelmaking practice is described in detail for the various furnaces and plants, the layout of plant and design of furnaces necessitating certain modifications of practice. Data are supplied for complete charges, with accounts of analyses of materials and details of pressure measurements. Recent modifications in furnace construction are referred to; and a very fully detailed account is given of the author's experience when working the standard hot metal process in cold-coke-oven-gas furnaces of modern design. The fuel consumption on these furnaces is given; for the more usual heating the gas supply and its utilisation are discussed, and results are given. Casting practice is described and the nature of the products indicated. Certain observations are made concerning points that experience indicates to be of prime importance or of special interest, including the supply of materials, the effect of furnace design or shop layout, and fuel.

Introduction.

In his Presidential Address to The Iron and Steel Institute at the Annual Meeting in April, 1937,[1] Mr. Alfred Hutchinson referred to the first visit of the Iron and Steel Institute to the Middlesbrough district in 1869, when a fully developed wrought iron and pig iron industry was in active operation. He stressed the point that these industries lost the initial heat of the liquid pig iron, and went on to show that the natural result of the presence in the district of a great number of blast-furnaces was that, following the adoption of the hot metal process by Sir Arthur Dorman at the Britannia Works, thenceforth the hot metal process became the rule in Cleveland for all basic furnaces.

This paper is designed to give a short account of the progress observed during the ten years during which the author has been

* Received July 9, 1937.

actively associated with the process, and to describe the details of the operation as carried out at the present time in five melting shops in the district.

It is ten or eleven years since a description of the hot metal process on the North-East Coast was published, and at the beginning of the section that is devoted to each melting shop a few figures are given, indicating the extent of the progress that has been made.

In this paper each melting shop is dealt with as an individual unit and its more important features and practice are described. There are points of dissimilarity in the plants and, owing either to construction or to general conditions within the individual works, some difference in the method of operation. It would not be possible to give for each plant precisely similar information in the same form; but the greater part of the information concerning plant and practice is set out in a manner designed to make comparison easy, while any item likely to be of interest or of use that concerns any one plant is given in the section devoted to that plant.

The Melting Shops.

I.—*Acklam.*

(1) *History.*

This melting shop building was originally erected to house two 400-ton tilting mixers that were installed in 1907 by the North Eastern Steel Co., Ltd., to serve their basic Bessemer plant. In 1919 it was decided to stop using the latter, and one of the mixers was converted to a 220-ton tilting furnace. This was put into service in 1921 and ran for some time at 1100–1200 tons a week, the low output probably being chiefly due to the small flues and inadequate natural draught. A second furnace was put into service in 1922, a tilting furnace of 140 tons capacity that was subsequently widened in 1929 to make it of the same capacity, namely 220 tons, as the third furnace that was started in 1923. This plant of a mixer and three tilting furnaces has run continually since 1923, and its output in 1924 was 1400 tons from each furnace, and in some cases over 1600 tons per week.[2]

(2) *Purpose and Present Capacity.*

The plant during the last nine or ten years has been worked to capacity. It has made over 6300 tons of ingots a week, nearly all in small sizes, that are rolled in the adjoining mill, the output of which is about 5200 tons a week of sheet bar, soft billets and small sections. The output of the plant when the three furnaces are working is more than the mill can use, but a stock has to be accumulated against the time when there is a furnace off for repairs. About 80% of the output is under 0·13% of carbon, and the greater part of it is rimming steel.

(3) *Layout of Plant.*

A plan of the melting shop is shown in Fig. 1, and a cross-section in Fig. 2.

The loading bay is 375 ft. long and 44 ft. wide. It is served by two 5-ton magnet cranes. There are three railroads in this bay, connected at various points, and, with the exception of dolomite, the whole of the cold materials for both the mixer and the furnaces are set on these roads. A long bench for charging boxes is situated at the side of this bay nearer to the furnace bay, and on the railroad adjacent to the bench the lime and limestone wagons are set. These materials are loaded into charging boxes by hand. The scrap, pig and Swedish ore are set in wagons on the further roads and loaded by magnet. It is possible to arrange the wagons so that the materials for a charge can be set opposite the furnace for which they are intended, thus saving crane time.

The furnace bay is 64 ft. wide and served by two 5-ton overhead revolving charging machines; one has a 5-ton, and the other a 25-ton auxiliary hoist which serves to tilt the blast-furnace metal ladles at the mixer. A railroad runs through the furnace bay close to the furnaces. This is convenient for any materials that it is desired to bring up ready loaded into charging boxes; on it are brought also crushed dolomite and the materials necessary for repairs and rebuilds.

The casting bay is 465 ft. long and 79 ft. wide. It has two 100-ton casting cranes, each with two 25-ton auxiliary hoists, one at each side of the main hoist. All casting is done on cars, the ladle being held by the crane. A casting platform runs the whole length of the bay, and the railroad adjacent to it may be entered either from the end or from a switch from a parallel road that also runs the full length of the bay. From the latter road curves go under each furnace, so that slag ladles may be set either under the launder or under the slag notch in the middle charging door.

The stripper bay is 225 ft. long and 79 ft. wide. It is provided with one 5-ton stripper crane, and three through railroads and one short road. There is good accommodation for mould storage.

(4) *Mixer.*

The rated capacity of the mixer is 400 tons. It is hydraulically tilted. The principal dimensions are: Length between blocks, 43 ft.; width inside lining, 16 ft. 6 in.; bath depth from foreplate, 5 ft. 8 in. Its checker chambers are the same size as those of the 250-ton furnace (Table XX.). Reversing is done by drum and butterfly valves. The fuel is producer gas and coke-oven gas, the producer gas entering through an ordinary gas port. A water-cooled tube lies along the floor of the gas port and adds the coke-oven gas to the producer gas at the mouth of the port. This coke-oven gas tube will supply sufficient gas to work the mixer in an

emergency; and in the past when repairs have been urgently needed to, perhaps, checkers or slag pocket roofs, and it has been wished to keep the mixer in service, the port block at the bad end has been moved back, a brick dam built to seal the end of the vessel, and coke-oven gas admitted through the tube in the good end. The mixer has on occasion worked three days in this way, not actively certainly, but well enough to give the furnaces the benefit of its storage capacity.

As has been indicated, the port blocks are movable. They are normally not moved, however, since the end of the vessel and the face of the port block are both circular and meet face-to-face with circular castings, around which a 6-in. strip is fastened. There is no loss of gas or breaking of draught when the vessel is tilted.

Metal is brought from the blast-furnaces in 30-ton ladles, which are set on the railroad that runs close along the charging side of the furnaces. The ladle is mounted on its carriage by a double trunnion. Normally, full or empty, the ladle distributes its weight between the two trunnions, and for emptying it moves about that trunnion nearer the mixer, the 25-ton auxiliary of the charging machine lifting the bottom of the side of the ladle remote from the mixer.

The outgoing metal is poured into a 60-ton ladle that stands on a weighbridge which has its beam on the charging platform level. It is poured into the steel furnaces by the casting crane.

The mixer is worked as actively as possible. It will melt easily 1000 tons of cold material a week, and usually it is necessary to put about this amount through, the average weekly amount for a three months' period being 950 tons. Of this amount about 62% is scrap, the remainder being pig, old moulds, &c. The cold charging is regulated according to the requirements of the steel furnaces and the availability of the charging crane. Some limestone is charged, but the ore additions are kept as low as possible.

The burden of the mixer as a three-months average is shown in Table II. The following figures give the average composition of the metal entering and leaving the mixer :

	C. %.	Si. %.	S. %.	P. %.	Mn. %.
Metal entering mixer . .	3·60	0·79	0·06	1·67	1·42
Metal leaving mixer . .	3·20	0·46	0·053	1·54	1·22

The fuel consumption is : Coal, 0·47 cwt. per ton of ingots; coke-oven gas, converted to coal, 0·26 cwt., making a total of 0·73 cwt. of coal per ton of steel ingots.

(5) *Furnaces.*

Of the three tilting furnaces, the one that was converted from a mixer is of 250 tons capacity; the other two are of 230 tons, and a longitudinal section of one of them is shown in Fig. 3. The principal dimensions of each are given in Table XX. The 250-ton

furnace has a semi-cylindrical shell and coned ends. The port blocks on this furnace are bigger structures than on the other furnaces, owing to the position of the regenerator chambers relative to the furnace. In other respects, except as indicated in the dimensions in Table XX., all three furnaces are constructed on similar lines. All furnaces have sloped back walls, and one a sloped front wall.

When putting in a new bottom, firebrick is first set across the width of the furnace to form an inverted arch of the desired curvature, and upon this 18 in. of magnesite is laid, keyed across the width of the furnace. The ends are similarly built on the curve, and the bottom is completed by fritting dolomite. The front linings are 18 in. of silica with metalcase magnesite pillars; the back linings, except the two hot-metal doors, are of metalcase magnesite, 18 in. at the foreplate level thinning down to 14 in. at the skewback. Fettling on these furnaces is carried right up to the skewback at the tapping side. There are five doors on the charging side, three used for charging, and the two end ones, which are smaller, for fettling and inspection. The roofs are of silica, with 12-in. and 15-in. ribs and a 15-in. panel over the middle charging door and over the tap-hole. On one furnace a 1-in. water pipe has been laid along the skewback channel at the charging side. The port blocks are carried complete in a cradle that may be lifted by hydraulic rams to allow the dipper plates to clear the edges of the water-seal tanks that surround each uptake. This need be done only when it is desired to move the port blocks right back; a 4-in. movement may be obtained with the water seal unbroken.

Each end of the vessel carries a water-cooled casting curved to the arch of the roof and adjacent to it, and two side chills that match the slope of others on the port block. A drawing of the arrangement of the chill castings on the port block face is shown in Fig. 4. The gas port arch is preserved by the torpedo cooling tubes, the nose ends of which are held in position between two arched pipes. The torpedo tubes are firmly held to the outside framework of the port block; there is 4½ in. of brickwork both above and below them. These port blocks need only a minimum of attention in the course of a seven or eight months' campaign.

Two of the furnaces are reversed by drum valves and butterfly valves; the third has Blaw-Knox gas and air valves.

The consumption of cooling water on each furnace is 750 gal. per min.; salt water is used, pumped direct from the river. No attempt is made to economise in water as it is collected and used at the blast-furnace gas washery.

One furnace has its regenerator chambers and slag pockets insulated with 4½-in. insulating brick built round the outside of the existing brickwork and held in place by light angle framework. This resulted in a saving of 0·22 cwt. of coal on that furnace, and it is intended that the rest of the furnaces shall be treated similarly.

The furnaces work with pressure air, and each is provided with a waste-heat boiler and fan. Draught gauges in the flues register to the charging stage, and two furnaces record the air checker temperature by thermocouples. The two smaller furnaces work with 0·80–0·90 in. W.G. draught in the air flue and mean checker temperatures of 1050° C. for gas and 1125° C. for air; the 250-ton furnace works with a draught of 0·75–0·80 in. W.G., gas checker temperature of 1050° C., and air checker temperature of 1100° C.

(6) *Products and Outputs.*

The make for the last four years has been principally sheet bar and soft billets, the proportion for the last year being sheet bar 79·7%, billets 20·3%. Most of the sheet bar is rimming steel of various grades, and much of the soft billet tonnage is also rimmed.

Table I. shows the average weekly output of the plant and the average weekly output of each size of furnace for the last five years.

TABLE I.—*Steel Production of Acklam Plant.*

Period.	Average Weekly Output of Shop. Tons.	Average Weekly Output per Furnace. Tons.	
		250-Ton Furnace. Tons.	230-Ton Furnaces. Tons.
Year ending 30/9/1932 . .	5467	1884	1807
1933 . .	5704	1912	1896
1934 . .	5333	1822	1756
1935 . .	5560	1870	1846
1936 . .	5631	1910	1885
Six months ending 31/3/1937 .	5684	1880	1902

In the years 1932 and 1933 the performance of the plant was improving. There was apparently a set-back in 1934, but the reduction in tonnage was due to the furnaces having to make 70% sheet bar instead of 80% structural steel. The average tap-to-tap time increased by 1½ hr., but it will be seen that by 1936 the tonnage under the new conditions is approaching that obtained under the old.

The record outputs are: Shop, 6315 tons; 250-ton furnace, 2357 tons; and the 230-ton furnaces, 2326 and 2205 tons per week.

(7) *Steelmaking Practice.*

The practice is designed so that soluble slag may be produced. Only two ladles of steel can be tapped at a time, so the interval of 35 min. after the first two ladles have been taken off is used for fettling the ends of the banks. After the last two ladles have been tapped off, about 6 tons of the finishing slag are removed, the rest being left to form the basis of the primary slag of the next charge.

Into this slag about 5 tons of burnt lime are charged, with about 22 tons of Swedish ore, and this is followed by half of the scrap. The rest of the ore and lime are next charged, about 14 tons of ore and 4 tons of lime, and the remainder of the scrap. This is complete about 5 hr. from tapping, and the whole of the mixer metal is added, which is usually done in four instalments, and the furnace is full about 6½ hr. from tapping. All the steel being required soft, the furnace is charged to melt at about 0·70% carbon. During melting, about 6 tons of slag are allowed to run off. The charge is usually about melted 13 hr. after tapping. After melting, the bath is fed down to about 0·40% carbon, and the greater part of the slag is removed. The slag has the following analysis :

CaO	42·5%	Total P_2O_5	16·82%
SiO_2	15·2%	Soluble P_2O_5	15·95%
FeO	5·0%	Percentage soluble	94·8%
Fe_2O_3	3·9%		

A new slag is made with lime and scale, and is gradually built up while working the carbon down to the required specification. The burden is always fairly free from sulphur, and no trouble is experienced in removing the phosphorus. The bath is tapped under a boiling but limey slag. Additions of double deoxidisers may be made to the bath in the case of non-rimming steels. To rimming steel, additions of aluminium are made to the ladle in accordance with a scale based upon the carbon content of the bath and the iron content of the slag. This addition provides almost standard conditions when teeming rimming steel, and only very occasionally has a controlling addition to be made in the moulds.

The average burden of the furnaces is shown in Table II., and the working of a typical charge in Table III.

TABLE II.—*Consumption of Materials in Hundredweights per Ton of Product.*

	Mixer.		
Molten metal	16·39	Limestone	0·14
Cold pig	0·64	Ore	0·08
Steel scrap	2·15	Dolomite	0·13
Old moulds, &c.	0·21		
Skulls, &c.	0·61		
	Steel Furnaces.		
Mixer metal	15·21	Lime	1·11
Direct metal	0·25	Limestone	0·13
Cold pig	0·27	Fluorspar	Nil
Old moulds, &c.	...	Dolomite	0·61
Steel scrap	3·88	Ferro-manganese	0·12
Skulls, &c.	0·29	Ferro-silicon	0·02
Mill scale	0·77	Ferro-phosphorus	0·005
Ores	3·09		

TABLE III.—*Working of a Typical Charge in a 250-Ton Tilting Furnace.*

Charge No. *A*791–794; June 12, 1937.

P.M.	
3.00.	Tapped two ladles.
3.15.	Fettling breasts and ends.
3.50.	Remainder of steel tapped.
4.10.	General fettling started.
4.50.	Fettling finished except top of back wall.
4.55.	Commenced charging burnt lime.
5.10.	5 tons 5 cwt. burnt lime charged.
5.15.	Finishing back wall fettling.
5.45.	Commenced charging ore.
6.10.	22 tons Swedish ore charged.
7.30.	30 tons scrap charged.
7.46.	13 tons Swedish ore charged.
7.50.	Started charging 30 tons of scrap, and 4 tons 4 cwt. of burnt lime.
8.30.	All cold material charged.
8.30.	55 tons mixer metal.
8.50.	52 tons mixer metal.
9.10.	50 tons mixer metal.
9.50.	44 tons mixer metal; analysis: Si 0·47%, S 0·05%.

A.M.	
2.05.	6 tons slag off.
4.00.	26 cwt. Swedish ore.
4.45.	6 tons slag off.
5.00.	6 tons slag off.
5.00.	Sample: C 0·40%, P 0·45%.
5.15.	4 tons burnt lime.
6.00.	35 cwt. scale.
7.30.	26 cwt. ore.
8.30.	21 cwt. burnt lime and 18 cwt. scale.
9.00.	14 cwt. burnt lime and 18 cwt. scale.
9.20.	Sample: C 0·25%, S 0·05%, P 0·20%.
9.45.	21 cwt. burnt lime, 18 cwt. scale, 12 cwt. ore.
10.35.	Sample: C 0·22%, P 0·08%.
10.45.	21 cwt. burnt lime, 12 cwt. ore.
11.10.	14 cwt. burnt lime.
11.15.	Sample: C 0·085%, Mn 0·17%, P 0·05%.
11.40.	14 cwt. burnt lime.
P.M.	
12.30.	Sample: C 0·085%, P 0·024%.
12.40.	Tapped.

Weight of ingots, 286 tons.

Pit Sample Analyses.

Cast No.	C. %.	Si. %.	S. %.	P. %.	Mn. %.	
*A*791	0·09	0·06	0·040	0·026	0·29	Semi-killed soft.
*A*792	0·09	0·014	0·039	0·065	0·40	High phosphorus, rimming.
*A*793	0·085	0·014	0·042	0·073	0·38	
*A*794	0·085	0·009	0·040	0·067	0·41	

(8) *Casting-Pit Practice.*

The ladles are of 75 tons capacity, and lined with 4½-in. Durham firebrick backed by a 1½-in. split. The average lining life is 18½ heats. The ladle is held by the crane during tapping, its height being adjusted to the moving launder. The crane holds the ladle during teeming. All steel is top-poured into moulds 18 in. × 18 in. at the bottom, 16 in. × 16 in. at the top and 6 ft. 0 in. long. Teeming is done by two stoppers through 1-in. fireclay nozzles. The moulds are smoked by pouring into each a small quantity of tar.

In view of the attention that has recently been focused on ingot moulds and their lives, the following experience of trouble consequent upon an increase of output may be of interest. The plant made its expansion of output, increasing its maximum by 1000 tons a week, during a period when the rolling mill was idle owing to trade depression, and, so far as the casting side was concerned, the expansion was accommodated comfortably because the steel was cast into 3½-ton ingots suitable for rolling at Britannia. Each casting car carried four moulds, and there were sufficient cars to allow the stripping and remounting to be done quickly enough not to keep the furnaces waiting. But when the Acklam mill restarted at the end of 1933 and needed an ingot of only 2 tons, the weight of steel that could be teemed on a car went down from 14 to 8 tons, and the supply of cars became inadequate for the plant. The emergency was met by designing a bottom plate with 6 in. overhang at each side of the casting car and getting six moulds on in two lines of three. This was equivalent to an increase of 50% in the number of cars; but the moulds were so close together that their lives were shortened considerably. It was essential to maintain six on a bogie, and the overheating was partly prevented by having some moulds made so that they could be set diagonally, with the stripping lugs on the corners instead of the sides. These could just be accommodated at the four corners of the car, with an ordinary mould in the middle of each row. There is no special cooling arrangement, and at busy times moulds are often used warmer than is desirable. The average life of the last 1530 moulds to be scrapped is 97 heats.

(9) *Fuel.*

The gas plant consists of a bank of 20 static water-bottom producers of 95 sq. ft. hearth area. Five are isolated to each furnace; normally at present only two per furnace are working. They are mechanically fed, but hand poked and cleaned. The coal used is a mixture of Yorkshire and Durham double nuts of the following average analysis: H_2O, 2·72%; ash, 3·98%; volatile matter, 32·26%; sulphur, 1·14%; fixed carbon, 59·90%. The producers are steam-jet-blown, the blast saturation temperature being 50° C. The fuel bed is 18 in. deep and each producer normally gasifies 11 cwt. of coal per hr. The gas is delivered into a separate main for each furnace; the pressure is normally set at 1·8-in. W.G. and is maintained by an Arca regulator on each furnace. The analysis of the gas is: CO_2, 5·8%; CO, 25·0%; CH_4, 2·9%; H_2, 12·6%; N_2, 53·7%. The tar content is 2·85 grains per cu. ft. and the moisture 29·3 grains per cu. ft. The gas is admitted to the drum valve by a mushroom regulating valve, where it is joined by coke-oven gas, the volume of which may be independently controlled by the melter. The use of coke-oven and producer gas as the

standard fuel was brought about by a series of adjustments that may be worth recounting.

(*a*) *Use of Mixed Gas.*—Prior to 1931 the furnaces were fired with straight producer gas from the static producers, but an increased output from the blast-furnaces and coke-ovens made it desirable that some of the furnaces should be fired by mixed gas. Accordingly, one furnace was converted to blast-furnace and coke-oven gas in December, 1930, and a second one in May, 1931. The results were not quite satisfactory; the outputs were not good. There was no gas holder in the works, and the supply of coke-oven gas was subject to considerable variation. Slag foaming trouble was experienced and luminosity of the flame was not always maintained. The trouble was probably due to the moisture of the wet cleaned blast-furnace gas.[3]

It is not considered necessary to publish the details of outputs and fuel consumptions of the mixed gas campaigns, since many works are now running on it very successfully, but the broad outline of the experience has been given in order to show how the present fuel practice was reached.

(*b*) *Use of Three-Gas.*—Since the mixed coke-oven and blast-furnace gas trial had caused irregularity in the performance of the plant, means were sought to get a fuel that would be substantially constant and yet provide useful work for the surplus gases. Accordingly, the three steel furnaces were equipped for the use of the three-gas mixture in January, 1932. The gases were proportioned arbitrarily, the first mixture being obtained by a rough setting of pressures and orifices which it was thought would enable the greatest possible amount of the two surplus gases to be used. The first setting, however, showed that there was considerable blast-furnace gas still available, and gradually the amount was increased, with a resultant drop in the calorific value of the mixture. The flame that was obtained from this leaner gas did not appear to be satisfactory, however, and as a result of extended careful observation the conclusion was reached that the dullness of the flame was possibly due to the extra moisture brought by the blast-furnace gas, coupled with the comparatively low calorific value of the mixture. The amount of the blast-furnace gas was therefore reduced, with a distinct improvement in the appearance of the flame, and the reduction was carried out progressively until by November, 1934, the blast-furnace gas was all off.

Fig. 5 shows the average consumption of blast-furnace gas per week, together with the average net calorific value of the three-gas mixture. These two curves meet and part as would be expected according to the variation of the amount of blast-furnace gas in the mixture. The third curve shows the output of normal "three-furnace" weeks during the period, and although, as is natural, the accidental variations in output are much greater than the variations in the gas mixture, the general tendency shows a better

performance with less blast-furnace gas in the mixture. It should be explained that the break across the middle of the graph denotes the point when the Acklam mill restarted and the steel requirements were 70% sheet bar instead of 80% constructional steel. There was a definite increase in the time of working charges due to taking the carbon content to a lower value; but it will be seen that both before and after the restart of the Acklam mill, the curves of calorific value and of output run in the same direction, and both are opposite to that showing the amount of blast-furnace gas.

Even though lower outputs were obtained after the restart of the Acklam mill, the fuel consumption per ton of ingots did not deteriorate, and this is considered to be due to the better thermal efficiency of the coke-oven/producer-gas mixture as compared with the three-gas mixture. Going still further, from October, 1934, to June, 1935, when the output had recovered most, but not all, of the lost ground, the fuel consumption was 0·17 cwt. per ton less than it had been in any of the previous periods.

(*c*) *Coke-Oven and Producer Gas.*—It will be apparent from a consideration of the experimental method by which the present fuel came to be used in these furnaces, that it is considered to be an eminently satisfactory one. The mixture is easily obtained and controlled and gives at all times a hot luminous flame that does not unduly endanger the furnace structure, and has proved to be economical.

(*d*) *Fuel Consumption.*—The total fuel consumption expressed as coal over the six-months period ending January 2, 1937, including the mixer and all lighting-up fuel, is 4·21 cwt. per ton of steel. Deducting the mixer figure of 0·73 cwt., the consumption on the furnaces, including lighting up, is 3·48 cwt. per ton, and excluding lighting up, 3·35 cwt. per ton.

(10) *Refractories.*

An accurate account has been kept for the last few years of the consumption of refractories on these furnaces, and Table IV. gives a record of the consumptions in the various parts of the furnace.

II.—*Britannia.*

(1) *History.*

The origin of this hot metal plant was referred to by the President in his Address.[1] From its early days the general layout of the plant remained substantially unaltered, and by improvements in furnace design and in practice, the outputs steadily increased, until between 1914 and 1925 the record furnace output had risen from 837 to 1105 tons.[2] At this time there were two tilting mixers of 200 and 400 tons capacity, serving two 80-ton and nine 45-ton fixed furnaces. In 1923 the 400-ton mixer was converted to a 250-ton tilting furnace, the average output of which was 1650

TABLE IV.—*Refractories Consumption of 250-Ton and 230-Ton Tilting Furnaces.*

	250-Ton Furnace.						230-Ton Furnaces.					
	Firebrick. Lb. per ton of ingots.	Ganister. Lb. per ton of ingots.	Silica. Lb. per ton of ingots.	Magnesite. Lb. per ton of ingots.	Chrome. Lb. per ton of ingots.	Totals. Lb. per ton of ingots.	Firebrick. Lb. per ton of ingots.	Ganister. Lb. per ton of ingots.	Silica. Lb. per ton of ingots.	Magnesite. Lb. per ton of ingots.	Chrome. Lb. per ton of ingots.	Totals. Lb. per ton of ingots.
Chamber walls and roof . . .	1·514	0·469	0·041	...	...	2·024	1·106	0·219	0·496	...	...	1·821
Checkerwork: Air .	3·573	0·725	...	...	...	4·298	2·549	0·887	...	...	...	3·436
Gas .	3·091	0·650	...	...	...	3·741	1·339	0·502	...	...	...	1·841
Uptakes and stoppers	0·441	...	4·518	...	...	4·959	0·412	...	4·963	...	...	5·375
Port block, roof, arches, &c. . .	...	...	1·612	...	...	1·612	...	...	1·897	...	...	1·897
General structure (bottom, launder, and all not otherwise accounted for)	4·814	...	0·006	0·127	0·435	5·382	4·668	...	0·036	0·013	0·036	4·753
Back lining . .	...	...	0·095	1·108	0·452	1·655	...	...	0·198	1·025	0·538	1·761
Front lining . .	...	...	1·021	1·554	1·032	3·607	...	...	1·070	1·398	1·103	3·571
Front arches and doors . . .	0·777	...	0·348	...	...	1·125	0·764	...	0·397	...	...	1·161
Roof . . .	...	...	3·318	...	...	3·318	...	...	3·941	...	...	3·941
Totals: . .	14·210	1·844	10·959	2·789	1·919	31·721	10·838	1·608	12·998	2·436	1·677	29·557

tons a week, until in 1929 a waste-heat boiler and fan were installed, when the output increased to over 2000 tons. Meanwhile the capacity of the fixed furnaces had been increased by deepening the baths, and in 1930, when the plant closed down owing to the trade depression, the small furnaces were working 55-ton charges and the 80-ton furnaces were tapping up to 120 tons. It was not until the end of 1933 that the plant was restarted, and as steel was urgently required the furnaces were put in commission without alteration. Every opportunity was taken to make improvements; the details furnished below will show to what extent the efforts were successful.

(2) *Purpose and Present Capacity.*

The plant serves the Britannia section mills, and nearly all the tonnage is structural steel. The present output averages about 4800 tons a week and rises to just under 6000 tons a week. A new 500-ton active mixer has been conveniently placed in the centre of the shop, and the old 200-ton mixer and six of the 45-ton furnaces have been scrapped. The removal of these has left the present units in a length a little more than half the original. The present working furnaces are the 250-ton tilting furnace, two 100-ton fixed furnaces (one built completely of " Radex ") and two 55-ton fixed furnaces.

(3) *Layout of Plant.*

A plan of the layout is shown in Fig. 6, and a cross-section in Fig. 7. The loading bay is 858 ft. long and 30 ft. 6 in. wide, and is spanned by four 3½-ton magnet cranes. Along this bay run two railroads, provided with three loops to facilitate shunting operations, and to these roads are brought all the solid materials for the mixer and furnaces. Between the roads and the charging stage is a series of charging-box benches on to which all materials are loaded direct from trucks.

The furnace bay is 1091 ft. long and 52 ft. wide, and houses the six furnaces and the mixer. It is served by four 3½-ton revolving overhead charging cranes.

The casting bay is 1091 ft. long and 47 ft. wide, and is served by four 75-ton casting cranes, which hold the steel ladle for casting and deal with metal in and out of the mixer. Three 10-ton steam jib cranes do the setting of moulds and stripping, casting being all done in sunken casting pits.

(4) *Mixer.*

The erection of the 500-ton mixer was commenced in the autumn of 1936, and it was lit up early in 1937. Its principal dimensions are: Overall length, 81 ft.; length from block to block, 57 ft.; width, 15 ft. 0 in.; and depth in the centre, 6 ft. 6 in. It is hydraulically tilted, and the gas may be kept on during tilting. The

bottom is 18 in. of magnesite brick with 1 ft. of dolomite. Linings are 18 in. of silica in front, and 18 in. of metalcase magnesite at the back. There are three charging doors and two smaller end doors in the front; all these doors have water-cooled jambs and arches. There are two doors in the back, one at each end, for inspection, fettling and charging hot metal. All the doors are hydraulically operated from the melters' central control point. Heating is effected by producer and coke-oven gas. The producer gas is taken from the common main, and the coke-oven gas is added by means of a long water-cooled tube lying along the inside of the gas port. The independence of the coke-oven gas supply makes it useful as an emergency supply and for the period at the week-end when the producer gas main is being burnt out. The port blocks are movable and are fitted with water-cooled ports. Metal is brought from the Acklam blast-furnaces in 28-ton ladles and is poured into the mixer by the casting crane. The metal is poured out of the mixer into a 50-ton ladle. About 1000 tons of cold material per week are melted in the mixer; this is necessary to provide the amount of molten iron needed by the steel furnaces, since the blast-furnaces send only about 2700 tons a week. This charging is regulated according to the requirements of the steel furnaces and the availability of charging cranes. A little limestone is charged to keep the slag in condition, but no ore, the refining that is obtained, as shown by the analyses of the metal in and metal out of the mixer, being effected by cold chargings. The physical condition and temperature of the metal as it comes from the mixer are good. There is no means of measuring the producer gas used on the mixer, so the fuel consumption cannot be separately shown. The consumption of cooling water is 650–700 gal. per min.

The burden, as an average over three months, is shown in Table VI. The following are the average compositions of metal entering and leaving the mixer:

	C. %.	Si, %.	S. %.	P. %.	Mn. %.
Metal entering mixer . .	3·60	0·78	0·053	1·66	1·36
Metal leaving mixer . .	3·20	0·46	0·045	1·44	1·03

(5) *Furnaces.*

The principal dimensions of the furnaces are given in Table XX.

The tilting furnace is, in general, similar to the Acklam furnaces (Fig. 3). It has sloped back and front walls, a back lining of 18 in. of metalcase magnesite at the slag line, thinning out to 14 in. at the skewback, and a front lining of 18 in. of silica with metalcase magnesite pillars. The roof is of silica, 12 in. thick, with 15-in. ribs. The port blocks are in every respect similar to those of the Acklam furnaces (Fig. 4). The furnace is equipped with gauges recording the draught in the air flues and the temperature of the air checkers.

The two 100-ton furnaces are in many respects alike, as may be seen from Table XX. One is built with silica in the usual parts; in the upper structure of the other, everything above the slag pocket roofs except the bottom itself is built of Radex. The roof is not in straight courses, but is bonded; it is 12 in. thick with 15-in. ribs, and is held at the tapping side on a spring-loaded skewback. Across the arch of the roof run channels curved to the contour of the arch, carrying longitudinal channels that form the bearing surface for a series of screws by which the rise of the roof can be regulated. The whole arrangement ensures that the contour of the roof is maintained right up to the end of its life. The front lining is of Radex, as is the sloped back wall. There are three charging doors with water-cooled jambs and arches and two small doors at the ends. Two wickets are provided in the back lining for inspection and charging hot metal. The port blocks are fitted with Moody water-cooled ports. The details of this port are shown in Fig. 8. This port has been made in many sizes and is at present built into a total of nine furnaces. It makes it possible to build a furnace with its blocks of the shortness that formerly had to be reached before the furnace gave its best performance, and this is what has been done with those furnaces of which, for some reason, the capacity could not be increased. Where, however, an increase of capacity was desirable, the port has enabled the bath to be lengthened by shortening the block. The port has given good results apart from the previous considerations, as it has preserved the flame direction right up to the end of the campaign and saved refractories while increasing the output. The furnace is equipped with gauges recording the draught in the air flues and the temperature of the air checkers.

The 55-ton furnaces have nothing out of the ordinary except Moody ports. The dimensions are given in Table XX.

The following are some particulars of the conditions under which the furnaces work: *The 55-ton furnaces:* Checker temperature, air 1110°, gas 1020° C.; draught in air flue before reversing valve, 0·55 in. W.G. *The 100-ton furnaces:* Checker temperature, air 1060°, gas 1000° C.; draught in air flue before reversing valve, 0·60 in. W.G.; draught in boiler flue, 1·45 in. W.G. *The 250-ton tilting furnace:* Air checkers 1120°, gas checkers 1030° C.; draught in air flue before reversing valve, 0·95 in. W.G.; draught in boiler flue, 1·25 in. W.G.

(6) *Outputs and Products.*

Almost the whole output of the plant is structural steel. Table V. shows the average weekly output of the plant and the average weekly output of each size of furnace for the last five years.

The record outputs are: Shop, 5,920 tons; 250-ton furnace, 2,362 tons; 100-ton furnaces, 1,661 tons; 55-ton furnaces, 1,071 tons per week.

TABLE V.—*Steel Production of Britannia Plant.*

Period.	Average Weekly Output of Shop. Tons.	Average Weekly Output per Furnace.		
		250-Ton Furnace. Tons.	100-Ton Furnaces. Tons.	55-Ton Furnaces. Tons.
Year ending 30/9/1932 .	Plant idle.	...	...	...
1933 .	,,	...	...	...
1934 .	3,375	1,331	1,082	640
1935 .	4,685	1,915	1,111	766
1936 .	4,873	1,800	1,230	810
Six months ending 31/3/1937	4,771	1,800	1,313	800

(7) *Steelmaking Practice.*

The practice on the tilting furnace is precisely similar to that used on the Acklam tilting furnaces, which has already been described in detail. The following description therefore refers to the fixed furnaces.

When a charge is tapped, while the steel is running out, the front breasts are fettled. As soon as all the steel is out of the furnace a rabble is tried over the bottom, and the bottom dried up. Fettling is then partly done, and charging starts soon after the tap-hole is closed. The fettling may be finished during the early part of the charging. Charging starts usually with about a quarter of the limestone, about 3 tons, followed by about two-thirds of the total amount of scrap. If this scrap is not very light material that has taken some considerable time to charge, it is warmed up for about half an hour. Then half the mixer metal is added, and the remainder of the limestone and the necessary ore are charged, followed by the remaining one-third of the scrap. This is quickly followed by the other half of the mixer metal; this time will be about $3\frac{1}{2}$–$3\frac{3}{4}$ hr. from starting to charge. During melting, slag is kept on for at least an hour, preferably two hours, but about 4 tons of slag are allowed to run off before the charge settles down. The bath is usually settled down, but not thoroughly melted, about 8 hr. from starting. The carbon is judged, the usual melting sample being between 0·65 and 1·00% carbon, and ore and possibly a little lime are fed until the carbon is estimated to be about 0·50%. A sample is then sent for analysis, and, if from the phosphorus content of the sample and the appearance of the slag it seems desirable, as much slag as is thought necessary is run off. A new slag is made with lime, scale and fluorspar, and usually both the sulphur and the phosphorus are removed quite readily. Later additions are made to keep the slag on the boil but sufficiently basic. The steel made is almost all of structural quality, and as soon as the carbon is 0·16% or under the charge is tapped. Additions are made normally in the ladle, except in the case of steels for

special requirements, alloy structurals, &c., when the greater part of the additions may be made in the furnace.

The foregoing account describes the working of a charge in one of the 100-ton furnaces. Similar procedure is followed with the 55-ton furnaces, except that in charging no metal is ever put in until all the cold material is charged. The 55-ton furnaces make any alloy steels that may be required.

The burden, as an average of three months, is given in Table VI., and the working of a typical charge is shown in Table VII.

TABLE VI.—*Consumption of Materials in Hundredweights per Ton of Product.*

Mixer.			
Molten metal	15·74	Limestone	0·21
Cold pig	1·30	Ore	...
Steel scrap	0·61	Dolomite	0·09
Old moulds, &c.	0·65		
Skulls, &c.	1·69		
Steel Furnaces.			
Mixer metal	13·40	Lime	1·31
Direct metal	0·54	Limestone	1·47
Cold pig	1·55	Fluorspar	0·07
Old moulds, &c.	...	Dolomite	0·56
Steel scrap	4·91	Ferro-manganese	0·16
Skulls, &c.	0·13	Ferro-silicon	0·03
Mill scale	0·76	Ferro-chrome	0·01
Ores	2·94	Silico-manganese, spiegel, &c.	0·004

(8) *Casting-Pit Practice.*

The casting ladles are of 60 tons capacity, and are lined with 4½-in. Durham firebrick with a safety lining of 1-in. split. The ladle life is 12 heats per lining. Teeming is direct from the casting crane, the ladle being moved over the moulds in the pit. Teeming is done by a single stopper through a 1-in. fireclay nozzle; all steel is top-poured, a small proportion being hot-topped. The ingot size varies from 2 up to 6 tons, all being narrow-end-up except the 2-ton size. The approximate sizes of the ingots are (quoting the larger end): 6 tons, 28 in. × 21 in. × 81 in.; 3½ tons, 26½ in. × 21 in. × 72 in.; 2 tons, 18 in. × 18 in. × 72 in. The moulds are tar-brushed before use. Stripping is done by three 10-ton steam jib cranes that lift the moulds off the ingots, which are then placed upright in cages and transferred by locomotive to the mills.

(9) *Fuel.*

The standard fuel used in this plant is producer gas. The only use made of coke-oven gas is for warming up furnaces before gassing, and on the mixer as described.

TABLE VII.—*Working of a Typical Charge in a 100-Ton Furnace.*

Charge No. *M*830; June 8, 1937.

P.M.	
3.00.	Charge tapped.
3.20.	Tap-hole closed.
3.45.	Started charging.
3.55.	3 tons limestone charged. Fettling meanwhile.
4.00.	Finished fettling.
5.30.	20 tons scrap charged.
6.05.	40 tons mixer metal charged.
7.00.	12 tons 12 cwt. Swedish ore, 9 tons 14 cwt. limestone, and 10 tons scrap charged.
7.25.	40 tons mixer metal charged; analysis : Si 0·46%, S 0·048%.
P.M.	
9.30.	4½ tons slag off.
11.30.	28 cwt. ore.
12.00.	56 cwt. ore, 27 cwt. burnt lime.
A.M.	
12.20.	Sample : C 0·26%, S 0·05%, P 0·20%.
12.30.	27 cwt. burnt lime, 30 cwt. scale, and 5 cwt. fluor-spar.
1.15.	Sample : C 0·20%, S 0·05%, P 0·07%.
1.20.	18 cwt. burnt lime.
1.40.	Sample : C 0·19%, Mn 0·20%, P 0·05%.
1.40.	27 cwt. burnt lime and 20 cwt. scale.
1.50.	9 cwt. burnt lime.
1.55.	Sample : C 0·145%.
2.00.	Tapped.

Weight of ingots, 115 tons.

Pit Sample Analysis.

C. %.	Si. %.	S. %.	P. %.	Mn. %.
0·24	0·06	0·036	0·039	0·79

The gas plant is composed of a single bank of eight 2-ton Morgan machines; two of them are separated for serving the mills, the remaining six providing all the gas needed for the steel furnaces. The coal used is mainly Durham, with Yorkshire coal to some extent in winter. The size is 50% single nuts, 50% double. The average analysis of the coal is : H_2O, 2·72%; ash, 3·98%; sulphur, 1·14%; volatile matter, 32·26%; fixed carbon, 59·90%.

Each machine has a hearth area of 95 sq. ft.; the fuel bed is maintained by a water-cooled leveller, and the ash is removed mechanically and transferred by an overhead telpher grab to an ash hoist. The air is induced by steam jet, the average saturation temperature of the blast being 52° C. The fuel bed is 20 in. deep and the gas leaves the producer at 700° C. The gas is delivered into a large hoppered dust main and then to a U-shaped dust trap, whence it passes to a common main. The pressure is automatically regulated, but has to be maintained at about 2½ in. at the producer end of the main in order to supply the comparatively large volume of gas needed by the tilting furnace at the farthest end of the main. Cross tubes lead from the common main to each furnace; all furnaces have mushroom valve regulation and are reversed by

means of drum valves. The gas has the following average analysis: CO_2, 4·9%; CO, 25·5%; CH_4, 3·0%; H_2, 14·8%; N_2, 51·8%. The tar content is 2·64 grains per cu. ft. and the H_2O content 19·8 grains per cu. ft.

Fuel Consumption.—The total fuel consumption over the six-months period ending January 2, 1937, including the mixer and all lighting-up fuel, is 4·84 cwt. per ton of steel.

III.—*Cleveland North Plant.*

(1) *History.*

About the year 1885 Messrs. Bolckow, Vaughan & Co., Ltd., built five Batho furnaces, first of 20 and then of 40 tons capacity, which were worked either on the scrap/pig-iron process or with partly blown metal from the Bessemer converters. The line of furnaces was extended between 1913 and 1915 by the construction of seven 60-ton fixed furnaces and two 400-ton mixers. Both the old and the new furnaces worked until 1921, when the Batho furnaces were shut down, eventually being scrapped. The extension, now the North Plant, was in continuous operation from 1913 to 1921, when it was closed down. In 1919–20 the furnaces were each making 700–750 tons per week.

In 1923 the plant worked with three furnaces and one mixer for a period of four months, and during 1927, two, and for a few weeks, three, furnaces worked on cold charging, but the plant was once more shut down in March, 1928. It remained idle until the autumn of 1936, when a decision was taken to bring it again into service, and some of the furnaces were pulled down with the object of remodelling them on more modern lines. The remodelling of the furnaces was completed by June, 1937, and by that time the previous record output of the shop, 4749 tons from six furnaces, had been raised to 6356 tons obtained from five furnaces.

(2) *Purpose and Present Capacity.*

The plant is intended to make about 6000 tons of ingots a week, normally with five furnaces working. Six furnaces only have been rebuilt; the upper structure of the seventh has been completely dismantled. The output in June, 1937, was about 5500 tons a week, approximately 1600 tons of rails, billets, &c., and the remainder structural steel. It is intended that the proportion of rails and carbon steels shall increase as the change-over in equipment becomes advanced. The units now rebuilt and commissioned are one 400-ton tilting mixer, fired with coke-oven gas (the second mixer stands idle), three 100-ton fixed furnaces, fired with producer gas, and three 100-ton coke-oven-gas-fired furnaces.

(3) *Layout of Plant.*

The essential features of the plant may be seen in Figs. 9 and 10. The casting bay is 58 ft. wide and has three casting cranes. One

crane is of 125 tons capacity and has one 25-ton auxiliary hoist; the other two cranes are of 100 tons capacity each with a 25-ton auxiliary hoist. The 125-ton crane takes the 100-ton heats that are at present being made in the coke-oven-gas-fired furnaces; the 100-ton producer-gas furnaces tap about 116 tons by means of bifurcated launders into two 65-ton ladles that may be handled by any of the three casting cranes. It is intended to put 125-ton cranes in the place of the two 100-ton ones; this will make the working more flexible, since then it will be possible to operate as many 100-ton single-ladle charges as may be desired. The charging side is served by two 5-ton revolving ground-type chargers and one 5-ton revolving overhead charger, this being the first step in a projected change-over to "all overhead." There is a 50-ton overhead crane with a 10-ton auxiliary hoist that is used to put metal into the mixer and do general lifting work about the plant. There is no stock bay or charging-box bench; all materials for charging are brought into the shop loaded into boxes, four or five boxes on a car. There are two railroads on the stage, both at the side remote from the furnaces, and they are connected by four loops. These roads are served by a ramp. A second ramp has been built at the opposite end of the shop, and it is expected that the serving of the mixer and furnaces will be greatly facilitated by the traffic being able to come in at one end and go out at the other, instead of having, as formerly, to go out by the way it came in.

(4) *Mixer.*

There are two mixers of identical design, one of which has not been again put into service. They are tilted hydraulically, and the rolling centre is the centre of the gas port. The capacity is 400 tons, the length from block to block 54 ft., the width from dolomite to dolomite at the foreplate level 16 ft. 6 in., and the maximum bath depth 5 ft. 9 in. The bottom and banks are of magnesite with dolomite rammed on, the linings and roof of silica with no special features. The mixer is fired by cold coke-oven gas, passed through two water-cooled nozzles into a combustion chamber. There is no difficulty in controlling the flame in the large vessel. The average fuel consumption of the mixer (gas converted to coal equivalent) is 0·70 cwt. per ton of ingots made.

Metal is brought from the blast-furnaces in 35-ton ladles, lifted through a hole in the charging platform by the 50-ton crane and poured into the mixer at the charging side. The ladle for dealing with metal out of the mixer is of 60 tons capacity, and stands under the launder on a weighbridge the beam of which is on the stage level. It is then put into the steel furnaces by the casting crane.

The mixer is worked as actively as possible, the amount of refining that can be done depending on the length of time between successive pourings-out and the amount of cold iron that has to

be melted. So far as cold melting is concerned, the mixer will do very well; at an output of 4000 tons of ingots it has melted 1100 tons a week of mixed pig and scrap, but it is not possible to get this amount through when the ingot output is 5000 tons or over, owing to the extra calls on the equipment.

The average mixer burden is shown in Table VIII. The following are the average compositions of metal entering and leaving the mixer:

	C. %.	Si. %.	S. %.	P. %.	Mn. %.
Metal entering mixer . .	3·96	1·21	0·058	1·33	1·27
Metal leaving mixer . .	3·65	0·86	0·041	1·23	1·07

(5) *Producer-Gas-Fired Furnaces.*

These three furnaces are essentially alike, the only dissimilarity being that the latest to go into service has water-cooled door jambs and door arches. The principal dimensions are given in Table XX. The furnaces were converted from 60 tons to 100 tons capacity by deepening the bath, flattening the end plate of the pan, and installing Moody ports, thus enabling the block to be shortened. The pan is lined with 15½ in. of common firebrick and 12 in. of magnesite, upon which 12 in. of dolomite is rammed in two furnaces and fritted in the third. Both the back and front walls are vertical and 1 ft. 6 in. thick. The front lining has metalcase magnesite pillars with silica jambs and arches (except where the water-cooled ones are introduced), and the back lining is all of metalcase, except the arches and jambs of the two back doors which are of silica. The roof is 12 in. thick with 15-in. ribs. It is not completely domed, but from the knuckle at each end rises 15 in. in 9 ft.; this gives a much better life to the middle of the roof. The height of the roof in the middle from the foreplate level to the underside of the roof skewback channel is 5 ft. 3 in. There are three charging doors; the middle one has a slag notch in the foreplate, from which slag may be run into a ladle set on the railroad that runs under each furnace from the valve arch. The dimensions of the regenerators are given in Table XX.; they are all steel-cased.

The reversing of these three furnaces is effected by butterfly valve for the air and Forter valve for the gas. The gas and air systems have separate flues to the stack, each with its own damper.

The average working conditions of the furnaces are: Checker temperature, gas 1081°, air 1190° C.; draught in air flue before reversing valve, 0·54 in.; draught at stack, 1·16 in.

(6) *Outputs and Products.*

As was explained at the beginning of this section, the plant has no history for the last ten years, having worked only a few months under modern conditions. The maximum week's make up to the beginning of July, 1937, was 6356 tons; the best output from a 100-ton producer-gas furnace working charges of up to 120 tons

was 1564 tons, and from a 100-ton coke-oven-gas furnace 1496 tons. The following are the qualities at present being made:

Rails	15·8%
Billets	13·0%
Structural	71·2%

(7) *Steelmaking Practice.*

The steelmaking practice on the producer-gas-fired furnaces need not be described, since details are given in section IV. (7) of the practice at the South Plant, and an account of the practice on the coke-oven-gas furnaces follows below; with a similar iron and burden the practice does not vary. The materials consumption, as a three-months' average, is given in Table VIII., and the working of a typical charge in Table IX.

TABLE VIII.—*Consumption of Materials in Hundredweights per Ton of Product.*

	Mixer.		
Molten metal	17·43	Limestone	0·29
Cold pig	2·20	Ore	0·28
Steel scrap	0·05	Dolomite	0·15
Old moulds, &c.	0·17		
Skulls, &c.	0·15		
	Steel Furnaces.		
Mixer metal	16·25	Lime	1·39
Direct metal	0·25	Limestone	1·43
Cold pig	1·38	Fluorspar	0·15
Old moulds, &c.	0·02	Dolomite	0·74
Steel scrap	2·31	Ferro-manganese	0·19
Skulls, &c.	0·14	Ferro-silicon	0·02
Mill scale	0·48	Silico-manganese	0·005
Ores	5·22		

(8) *Cold Coke-Oven-Gas-Fired Furnaces.*

The furnaces are of Hoesch design, and details of their performances at Hoesch Köln-Neuessen have been given by O. Schweitzer.[4] At those works, however, the furnaces had not been worked on 90% hot metal of such composition as that which Cleveland works, and therefore it may fairly be said that these are the first results to be published of the operation of cold coke-oven gas-firing with ordinary hot-metal practice involving large slag volumes.

An outline of the upper part of the furnace is shown in Figs. 11 and 12, from which it will be seen that it is similar to that described by Schweitzer,[5] an illustration of which was reproduced by Wesemann in his paper read at the Autumn Meeting of the Institute in 1936.[6]

The furnace was designed to work a charge of 100 tons, and allowance was made for a slag volume of about 16%, but, owing to circumstances that could not have been foreseen, the furnace has had to be worked on a larger proportion of hot metal than was anticipated, and the slag volume has been about 25%. This has meant that the 100-ton charge has stood up higher on the banks

TABLE IX.—*Working of Typical Charge in a 100-Ton Producer-Gas Furnace.*

Charge No. *N*1758–1759; June 17, 1937.

P.M.		A.M.	
5.00.	Charge tapped.	2.00.	14 cwt. burnt lime.
5.30.	Tap-hole closed.	2.42.	Sample: C 0·39%, S 0·071%, P 0·28%.
5.50.	Fettling finished.	2.45.	28 cwt. burnt lime and 10 cwt. fluorspar.
5.50.	Charging started.	3.30.	14 cwt. burnt lime and 12 cwt. scale.
6.15.	12 tons 10 cwt. scrap charged.	4.00.	Sample: C 0·31%, S 0·053%, P 0·11%.
7.40.	6 tons 8 cwt. limestone, 32 tons Swedish ore charged.	4.10.	14 cwt. burnt lime.
8.40.	52 tons 10 cwt. mixer metal.	4.30.	14 cwt. burnt lime and 12 cwt. scale.
9.30.	55 tons 3 cwt. mixer metal; analysis: Si 0·70%, S 0·060%. Metal delayed by tapping other furnaces.	5.10.	Sample: C 0·22%, S 0·046%, P 0·07%.
11.00.	Started slagging.	5.30.	14 cwt. burnt lime.
12.00.	11 tons slag off.	5.45.	14 cwt. burnt lime.
A.M.		5.55.	Sample: C 0·155%, S 0·040%, P 0·039%.
12.05.	14 cwt. burnt lime.	6.05.	7 cwt. burnt lime. Awaiting result of sample.
12.30.	14 cwt. burnt lime.	6.30.	Tapped.
1.00.	14 cwt. burnt lime.		
1.30.	14 cwt. burnt lime.		

Weight of ingots, 121 tons 4 cwt.

Analyses.

Cast No.	C. %.	Si. %.	S. %.	P. %.	Mn. %.
*N*1758	0·19	0·03	0·040	0·031	0·62
*N*1759	0·20	0·03	0·040	0·030	0·58

of the furnace than it should have done, and that the end banks and the table have had to be fettled with dolomite, thus somewhat reducing the area of the entrance to the combustion chamber.

The furnace is 64 ft. long over the port ends, 48 ft. 6 in. long between the cooling frames of the port ends, and 42 ft. long at the foreplate level. It is 11 ft. 6 in. wide from dolomite to dolomite at the foreplate level. The entrance to the furnace from the combustion chamber is 6 ft. 1 in. wide and is formed by the shoulders of the furnace and an arch 9 in. thick thrown across the width of the combustion chamber. This " intermediate roof " (*Zwischengewölbe*)

has become known, incorrectly but conveniently, as a "relieving arch," and was developed by the designers of the furnace in their own works, to preserve the main roof during the early part of a campaign. There is only one uptake, measuring 3 ft. 3 in. × 6 ft. 4 in. at the foreplate level, and it gradually widens out to join the slag pockets.

The roof of the furnace is domed from end to end, and arched as usual from back to front. It is of silica, bonded and ribbed, 12 in. thick with 16-in. ribs. The upper end of the tapping side buckstaves are held by springs attached to transverse tie bars, so that the rise of the roof during heating-up may be very closely controlled by adjustment of the nuts and the cushion effect of the springs. This arrangement has worked very well; the nuts holding the springs have been slacked back during heating-up and the rise in the roof limited to 1½ in. on the crown, and every roof has been brought up to working temperature in perfect condition. The hearth is 2 ft. 2 in. deep, and the bottom is made with 13½ in. of magnesite brick with 12 in. of dolomite, half rammed and half burned on; the linings are built according to the Company's usual practice, namely, silica jambs and arches in the doors and metal-case magnesite pillars, and a metalcase magnesite back wall. There are two cooling frames at each end of the furnace, one that extends up the sides of the gas port eventually to form a tank 4 in. wide between the end of the main roof and the port end roof, and the other shaped to the contour of the relieving arch, with, from the highest point of the arch, a vertical extension by which the water is led out (Fig. 13).

The consumption of cooling water is 500 gal. per min.

There are three charging doors, the middle one having a slag notch in the foreplate. Two doors are now built into the back wall for charging hot metal, inspection and fettling. The North Plant coke-oven-gas-fired furnaces are all converted from producer-gas firing, and the old gas and air chambers are connected at the slag pockets and at the outgoing flue. There is also a series of arched passages cut through the wall dividing the old gas and air chambers. There are four holes at each end—semicircular, each about 2 ft. in dia.—and they help to equalise the pressures in the two chambers. The chambers are steel-plated and insulated with 4½ in. of insulating brick. They are 22 ft. long to the bridge; the outer one is 8 ft. 9 in. wide, the inner one 9 ft. 9 in. wide. The centres of the buttressed 4½-in. bearer walls are 2 ft. apart and the walls are 4 ft. 6 in. high. The distance from the top of the bearer blocks (above the top of the bearer walls) to the top of the bridge wall is 13 ft. 6 in. There are 36 courses of checkers, 9 in. × 4½ in. × 3-in. brick set with 6 in. × 6-in. straight-through openings, the top six courses being of silica and the rest of Scottish firebrick. The inner flues leading from the bottom of the chambers, before they join each other, are 5 ft. 9 in. wide and the outer ones 6 ft. 3 in. wide, and

the common flue is 6 ft. 9 in. in mean height and 7 ft. 0 in. wide. Straight-through slide valves are fitted, the openings being 7 ft. wide and 6 ft. high.

The furnace is worked by natural draught, and the waste gases go by way of a short flue, 4 ft. 6 in. wide and 9 ft. 5 in. high, to a brick-lined steel chimney 150 ft. high and 6 ft. in dia. inside the brickwork.

The air is supplied by a fan capable of delivering 1·05 million cu. ft. per hr. at 4 in. W.G., and an orifice plate for measuring purposes is fitted on the delivery side.

The coke-oven gas is brought in a 24-in. main to the end of the melting shop, where it is boosted to a pressure of 17½ in. W.G. in the 24-in. main that runs along the valve arch the whole length of the shop. This pressure is maintained constant by an Askania regulator and graphically recorded. Gas connections 12 in. in dia. are led off to each coke-oven-gas-fired furnace, and in each of these connections is an orifice for metering purposes and a butterfly regulating valve and a sluice valve for isolating the furnace from the gas main. The main forks to the ends of the furnace, and at each end turns vertically through the platform on the centre line of the furnace. About a foot above the platform this vertical main has a hand-operated sluice valve, and immediately below this a hydraulically-operated quick-acting sluice valve, operated from the melters' control point, by which the reversals are made. Above these two valves the main forks Y-fashion. Each upper leg of the Y has a hand-operated sluice valve by which either burner may be shut off at will. Immediately after these uppermost sluice valves, the vertical mains connect by means of a water seal with a welded goose-neck, to the farther end of which the burners are fixed (Fig. 13). The burners, which are water-cooled, are 3½ in. in internal dia. They are carried, in openings that allow room for movement, in a water-cooled frame that lies flat against the bulkhead. This frame, and with it the burners, is adjustable for height, and by means of screws attached to the frame and to the burners the latter can be adjusted sideways. With this arrangement a very accurate setting of the burners can be made. The setting satisfactorily made, the space round the burners is closed with bricks and clay. On the centre line of the burners and remote from the furnace is an opening by which the inside of the burners may be inspected. It has been found that the insides of the burners get very slightly dirty; on inspection nothing can be seen, but after rubbing them out with a piece of sacking on the end of a rod they permit the passage of sometimes as much as 20,000 cu. ft. per hr. more gas with the same setting of the regulating valve. This cleaning has to be done about twice a week. The inspection opening is normally closed by an explosion disc.

The gas and air are both metered by orifice plates, the differential pressures from which are transmitted to a duplex ring-balance-type

instrument which indicates and records the air flow and indicates, integrates and records the gas flow. The indicating scales are arranged so that when a 5 : 1 air/gas ratio is being maintained the pointers are opposite each other. A typical chart produced by the instrument is shown in Fig. 14.

Tar is admitted to the furnace through two burners at each end, one at each side of the combustion chamber. It is delivered to the burners at a temperature of 180° F., and at a pressure of 60–80 lb. per sq. in. Compressed air at a similar pressure is injected into the barrel of the burner, and the discharge of the tar mixture through a small orifice of approximately 2 mm. bore produces a sufficiently fine degree of atomisation. The burner is water-cooled, and the tip projects about 6 in. into the combustion chamber. The tar is supplied to each burner by its own pump, and when once the burner is adjusted to give a spray correct in alignment and satisfactory in amount, the supply may be stopped and restarted by an operating switch controlling the pump motor.

Operating the Furnace.—After a charge has been tapped, the bottom is dried up, the tap-hole closed, and the furnace fettled. Fettling is usually completed and charging started about 50–55 min. after tapping. The gas is put up to about 125,000 cu. ft. per hr. and the air to 725,000 cu. ft., and about 14 tons (all these figures of quantity are the average of 80 consecutive charges) of scrap are charged on the bottom. Most of the charging is done through the end doors, cold stock being very quickly heated through at the end at which the gas is on. When the first few charges were made it was found that unless most of the cold material was charged in the ends of the furnace the middle was too long clearing from the bottom. By the time the scrap, which is mostly scrap from section finishing mills, is charged it is warmed through, and 7½ tons of limestone and 24 tons of Swedish ore are charged. Pig iron to the amount needed (average 7·3 tons) is then charged. In about a quarter of an hour about 47 tons of mixer metal are added, and in another 25 min. the remainder to make up a total of 84 tons of mixer metal. Under good conditions the furnace is full 1¾ hr. after starting to charge. There is usually a good reaction, and the slag is kept on if possible for about an hour or more. The reaction then becomes less violent, and instead of the slag boiling roughly it tends to foam. At this point the brickwork of the furnace would rapidly become overheated if gas alone were used, so the gas is cut down to about 80,000 cu. ft. per hr., the air to 550,000–600,000 cu. ft., and the tar spray is started. The quantity of tar is not varied, but is kept at a constant rate of about 500 lb. per hr. From then onwards the furnace simply works like any other hot-metal furnace, except that, in the Company's 17 weeks' experience, there is never any trouble in reaching tapping heat. As much of the primary slag is run off as is thought desirable, and the charge is fed and worked

in the usual way. There is no trouble in keeping the brickwork cool—less than with many producer-gas furnaces.

A record of the working of a typical charge is given in Table X., and its gas and air consumption chart is reproduced in Fig. 14.

TABLE X.—*Working of a Typical Charge in a 100-Ton Coke-Oven-Gas-Fired Furnace.*

Charge No. *N*1695; June 11, 1937.

P.M.	
11.25.	Charge tapped.
12.00.	Tap-hole closed.
A.M.	
12.25.	Fettling finished.
12.25.	Charging started.
12.35.	10 tons 11 cwt. scrap charged.
1.15.	6 tons 8 cwt. limestone and 26 tons Swedish ore charged.
1.30.	11 tons 13 cwt. pig iron charged.
2.10.	44 tons 10 cwt. mixer metal.
2.40.	40 tons 0 cwt. mixer metal; analysis: Si 1·25%, S 0·044%.
3.15.	3 tons slag off.
5.00.	6 tons slag off.
6.05.	42 cwt. burnt lime.
6.30.	30 cwt. ore, 28 cwt. lime.
6.43.	Sample: C 1·73%, S 0·043%, P 0·26%.
A.M.	
6.55.	30 cwt. ore, 28 cwt. lime.
7.30.	30 cwt. ore, 14 cwt. lime.
8.30.	3 cwt. spar, 5 cwt. scale.
9.00.	3 tons slag off.
9.07.	Sample: C 0·80%, S 0·04%, P 0·039%.
9.30.	14 cwt. lime.
10.03.	Sample: C 0·65%, P 0·030%.
10.15.	14 cwt. lime.
10.38.	Sample: C 0·62%.
10.40.	Slag sample: Fe 6·0%.
10.45.	14 cwt. lime.
11.00.	7 cwt. lime.
11.10.	7 cwt. lime.
11.12.	Sample: C 0·55%, P 0·028%, Mn 0·07%.
11.25.	Sample: C 0·54%, Mn 0·06%.
11.37.	Sample: C 0·53%.
11.45.	Tapped.

Weight of ingots, 105 tons 10 cwt.

Analyses.

	C. %.	Si. %.	S. %.	P. %.	Mn. %.
Pit sample	0·62	0·13	0·033	0·035	0·77
Ordered	0·60–0·63	0·12	0·04	0·04	0·74–0·78

TABLE XI.—*Output and Fuel Consumption of the Three Coke-Oven-Gas Furnaces.*

	First Furnace.	Second Furnace.	Third Furnace.
Normal Weekly Tonnage:	1198.	1083.	1242.
Fuel consumption. Million B.Th.U. per ton of ingots — By gas	4·64	4·66	3·43
By tar	0·56	0·73	0·84
	5·20	5·39	4·27

So far as the refractories consumption is concerned, no figures are available yet; the furnaces have not been long enough in operation, but the general impression is that the consumption will be light.

Table XI. shows the outputs and fuel consumption that have been obtained. The first furnace was started at the end of January, 1937, the second at the beginning of March, and the third in the middle of April.

Some details of the working conditions of the furnaces are given here as average values:

Average net calorific value of coke-oven gas .	470 B.Th.U. per cu. ft. wet at 62° F.
Calorific value of tar	16,500 B.Th.U. per lb.
Temperature of checkers	1213° C.
Draught in downtake	0·31 in. W.G.
„ checker chamber . . .	0·82 „
„ flue	0·96 „
„ chimney	1·25 „

Average waste gas analyses:

	Furnace Downtake.	Base of Stack.
CO_2	10·6%	7·0%
O_2	4·0%	10·4%
CO	Nil	Nil

The weights of the various materials used in the burden have been mentioned in the text, but are also shown in Table XII., together with the minimum and maximum amounts that have been used in the 80 consecutive charges.

TABLE XII.—*Materials Composing Charge of Coke-Oven-Gas Furnaces.*

Material.	Average Weight.	Minimum Weight.	Maximum Weight.
	Tons. Cwt.	Tons.	Tons.
Steel scrap	14 3	9¼	24½
Cold pig iron	7 6	Nil	29
Limestone	7 8	6½	9¾
Swedish ore	24 1	19½	28
Mixer metal	83 17	50	96

The average analysis of the mixer metal used was:

C, 3·65% Si, 0·86% S, 0·041% P, 1·23% Mn, 1·07%

General Observations on the Performance of the Coke-Oven-Gas-Fired Furnaces.—In examining the results of this four months' work it should be remembered that the plant is, in effect, a new plant added to an existing, running organisation. In December, 1936, the first producer-gas furnace was started, on direct metal; and at

that time the total ingot output of the works was 7800–8200 tons from the South Plant. In the succeeding five months furnaces have been added, until the total ingot output of the works in June reached 13,000 tons.

It will be realised that such an expansion period does not allow the best results to be obtained from individual units; there have been delays to the furnaces at times owing to the pressure put on to the services and on to equipment in process of being altered or renewed. The outputs show that the second furnace did not do so well as the first, but the third did better. The second furnace was unfortunate; trouble was experienced in maintaining a satisfactory supply of tar to the furnace; and it can be most definitely stated that, unless the " Hoesch " process is worked, steel cannot be made with a hot metal practice such as this without carburising. The slags that have to be carried, particularly in the early boiling stages and any time with high carbon contents, will foam up immediately the tar is stopped. The brickwork quickly becomes hot; but when the tar is restarted the bath at once boils and the brickwork cools down. The tar trouble was corrected for the third furnace; and another important help was that the melters, none of whom had previously worked with cold coke-oven gas, were becoming trained in its use.

Considering all these points, it is not unreasonable to hope that longer experience will show that North-East Coast hot-metal practice can be worked with cold coke-oven gas and some form of carburising, at least as efficiently as by any other method of heating.

(9) *Casting Pit Practice.*

There are two sizes of ladle in use at present, 100 tons and 65 tons. Both are lined with 4½-in. brick in addition to a safety lining of 1½-in. split. Common Durham firebrick are used; it is too early to say what is the life of the ladle linings. Each ladle has one stopper with bolt and cotter head attachment; 1¼-in. fireclay nozzles are used. There are three teeming platforms, all casting being done on cars. The ladle is held in the crane. All steel is top-poured. Mould preparation is limited at present to smoking the mould wall by means of a small piece of pitch put into each mould, and to an endeavour, not always successful, to arrange the interval between successive casts in the same moulds long enough to avoid getting a batch of stickers. There is only one record available of mould life; a set of one hundred 3-ton open-ended moulds has been used up and has given an average life of 90 heats.

(10) *Fuel.*

All the details concerning the fuel supply and its use on the cold coke-oven-gas-fired furnaces have been given earlier in this section, so only the producer-gas furnaces will be considered here.

When the reconstruction of this plant was undertaken in 1936, a bank of fixed water-bottom gas producers that ran along the whole length of the shop was taken out. As some of the furnaces were to be fired with cold coke-oven gas, the necessary gas plant for the remaining furnaces would not take up much space, and accordingly the machines were erected at the east end of the building. The plant consists of one 3-ton Morgan machine, similar in every respect to those on the South Plant and described in section IV. (9), and one 2-ton Wellman machine. The Wellman gasifies 35–40 cwt. of coal per hr. It is mechanically fed, poked and cleaned. It has not yet been necessary to put it into service, as, up to the present, the Morgan has been able to make all the gas needed. The gas is led through the producer sealing-off valve into a hoppered dust-catcher whence it passes to the common main that extends up to the *R* furnace. The gas pressure is kept constant at about 1·4 in. in the main, being increased when necessary towards the end of the week to overcome soot deposits. The volume of gas passing to each furnace is controlled by an ordinary mushroom valve, and coke-oven gas is admitted by the melters' regulation of a sluice valve in a 4-in. pipe opening into the section of the producer-gas main leading to the mushroom valve, thus ensuring a good mixing of the gas.

Fuel Consumption.—The fuel consumption of the producer-gas furnaces, from the restarting of the plant, including the heavy lighting-up consumption and including the mixer, is 4·88 cwt. per ton; excluding the mixer but including lighting up, 4·18 cwt. per ton of steel.

IV.—*Cleveland South Plant.*

(1) *History.*

The erection of this plant was started during the war to meet the great demand for steel, but the first furnace was not started up until 1918. By the end of 1921, seven of the eight furnaces were working. The North plant was laid off, and since that time, excluding the 1926 stoppage, the plant has been in continuous operation, but at varying capacity, to the exclusion of the North plant. A full description of the plant as originally laid out was given in the technical press in 1921,[7] but it has been considerably altered since that time. It consisted originally of eight 60-ton basic furnaces and two semi-active 400-ton mixers, all fired from a bank of 30 static water-bottom gas producers. The average make per furnace, with two mixers working, in 1926 was 850 tons per week. In 1927 the fixed furnaces were enlarged from 60 to 75 tons capacity, and in 1928 one of the mixers was converted into a 150-ton tilting furnace, and subsequently in 1930 into a 230-ton tilting furnace. One of the 75-ton furnaces was altered early in 1937 to 140 tons capacity and has only recently been put into operation.

(2) *Purpose and Present Capacity.*

The present maximum output of the plant is 8790 tons a week. It runs on an average of about 7500 tons, making rails of all kinds and plain carbon steels over a wide range for the Sheffield trade and other users of first-class semi-finished material. The units at present operating are the 400-ton mixer, a 230-ton tilting furnace, five or six 75-ton fixed furnaces, and a 140-ton fixed furnace.

(3) *Layout of the Plant.*

The plant as it exists at present is illustrated by Figs. 15 and 16.

The furnace bay is 1025 ft. long by a 77-ft. span, and is served by four charging machines of the revolving low-ground type and two 50-ton overhead cranes, each with a 10-ton auxiliary hoist. The plant is designed essentially for hot-metal practice, as it has no stock or loading bay, but on the side remote from the furnaces there are two railroads inter-connected by four loops along which all cold materials for the mixer and furnaces are brought ready-loaded in charging boxes. The cars containing the boxes are set on the road nearer the furnaces, and it is possible to have the four charging machines working simultaneously.

The casting bay is 1025 ft. long by 68 ft. 5 in. span, with two 100-ton casting cranes, each with a 25-ton auxiliary hoist. Casting is done from fixed stands, the bogies carrying the moulds being moved by a horizontal hydraulic ram. The next bay was formerly a stripper bay, but as the stripper crane has been moved to the rolling-mill soaking-pit bay, it is now used for marshalling rakes of casting cars and for mould stocking, preparation and setting.

Producer gas is now supplied by five Morgan gas machines, delivering by way of dust-catchers into a common main. The mixer and each furnace are provided with a waste-heat boiler and fan. All materials intended for the plant, such as ferro-manganese, ferro-silicon, &c., are prepared outside and brought up in charging boxes, which may be set at convenient points, while the dolomite is brought up in totally-enclosed steel bins and tipped as required.

(4) *The Mixer.*

The mixer has a capacity of 400 tons. It is operated hydraulically and rolls round the centre of the gas port, so that the gas may be kept on while tilting. It is 91 ft. 0 in. long overall, 49 ft. from block to block, and 16 ft. 6 in. wide from dolomite to dolomite at the foreplate level. Its maximum bath depth is 5 ft. 0 in. The bottom is lined with 4½ in. of firebrick and 14 in. of magnesite carried up the banks to 1 ft. 3 in. above the foreplate level. The working bottom consists of 1 ft. 6 in. of rammed dolomite. The front lining is 18 in. thick, all silica, and has three charging doors. The back lining is 18 in. thick and is completely built with metal-case magnesite. There are two back doors, with silica jambs and

arches. The roof and ramps are 12 in. thick of silica all through. The mixer was originally fired by producer gas through the ordinary gas port, and although the design of the port has not been altered it is now working satisfactorily with a mixture of blast-furnace and coke-oven gas. Reversal is effected by butterfly air valve and drum gas valve. Natural air is used. Draught is provided by a fan working with a waste-heat boiler.

Metal is brought from the blast-furnaces in 35-ton ladles, lifted through a hole in the charging platform by the 50-ton crane, and poured into the mixer at the charging side. The ladle for metal out of the mixer is of 60 tons capacity and stands under the launder on a weighbridge the beam of which is on the stage level. It is then put into the furnaces by the casting crane.

The mixer is worked as actively as possible, but it is not possible to charge any great amount of cold material when the shop is making round about 7500–8000 tons of ingots per week. The calls on the mixer for iron are very frequent, and the charging-side equipment is kept busy serving the furnaces. A small amount of scrap is melted, and most of the refining is done by ore, care being taken to ensure that the metal coming out of the mixer is hot. The average burden of the mixer is shown in Table XV., and the refining it does is shown by the following analyses :

	C. %.	Si. %.	S. %.	P. %.	Mn. %.
Metal entering mixer . .	4·00	1·21	0·064	1·40	1·28
Metal leaving mixer . .	3·67	0·83	0·051	1·25	1·02

The average fuel consumption of the mixer (gas converted to coal equivalent) is 0·58 cwt. per ton of ingots.

(5) *Furnaces.*

230-*Ton Tilting Furnace.*—When the furnace was first altered from a mixer, a false bottom of curved steel joists was put in to give the shallow bath that was considered necessary. It worked at 150 tons capacity, and under these conditions made an average of 1200 tons a week. In 1930 it was decided to increase the capacity to 230 tons, so the false bottom was removed and the new lining was put in from the original plates. The principal dimensions of the furnace are given in Table XX. The bottom now has 4½ in. of firebrick and 18 in. of magnesite, completed by 16 in. of dolomite fritted on. The front lining is of silica, 18 in. thick, and the back lining of metalcase magnesite, 18 in. thick. The roof is of silica, 12 in. thick, with 15-in. ribs. The furnace has three charging doors and a smaller door at each end, and two doors in the back lining. The port blocks are movable, with water seals, and are built exactly as described for the Acklam furnaces and illustrated in Fig. 4. The regenerator chambers and slag pockets are steel-cased. The furnace is provided with pressure gauges for recording the draughts in the gas and air flues and the boiler flue, and works with 0·75 in. W.G. draught in the air flue and 1·20 in. W.G. in the

boiler flue. The average gas checker temperature is 1090°, the air checker temperature 1174° C. Reversal on this and all other furnaces in the shop is done by butterfly air valve and drum gas valve.

75-*Ton Furnaces.*—The principal dimensions are given in Table XX. Although the furnaces were designed only for 60 tons, it will be seen from the figures that they were built on very generous lines, the length of the checkerwork having been actually 4 ft. longer than it is at present; this 4 ft. has now been added to the slag pockets. Many of the furnaces are still working with the bottoms that were put in some years ago, with compressed dolomite bricks, but when a furnace bottom is renewed it is now built with 4½ in. of firebrick and 13½ in. of magnesite, upon which the dolomite bottom is fritted. The linings are 1 ft. 6 in. thick, the front lining of silica, and the back lining of metalcase magnesite, except the two back doors, the arches and jambs of which are of silica. The roof is of silica, 12 in. thick, with 15-in. ribs. Each furnace has three charging doors, which are hydraulically operated. The cross-section of the plant, Fig. 16, is taken through one of these furnaces.

The furnaces work with 0·50 in. W.G. draught in the air flue, and 0·90 in. W.G. in the boiler flue. The checker temperatures are 1110° for gas and 1220° C. for air.

140-*Ton Furnace.*—The capacity of this furnace was obtained by increasing the angle of slope of the end plate of the pan, and deepening the bath to 3 ft. 0 in. It was possible to use a shorter block by installing a Moody port. The roof was left of the same thickness, but was lifted in the middle as is shown. No alteration was made in the width of the furnace, the construction of the linings being similar to those of the other furnaces, and no alteration was made in the checkers. A longitudinal section is shown in Fig. 17. The average values of the measurements that have been taken during the short time that this furnace has been in operation are: Draught in air flue, 0·45 in. W.G.; draught in boiler flue, 0·85 in. W.G.; checker temperatures, air 1192°, gas 1106° C.

(6) *Outputs and Products.*

Table XIII. gives as percentages the amounts of various steels made over a twelve months' period.

TABLE XIII.—*Steels made at Cleveland South Plant in the Year ending September* 30, 1936.

Billets under—		Rails	20·8%
0·12% carbon	4·4%	Structural	49·2%
0·12–0·25% carbon	5·7%	Alloy structural	0·6%
0·25–0·50% carbon	6·5%	Castings	0·1%
0·50–0·75% carbon	10·8%		
over 0·75% carbon	1·9%		100·0%

Table XIV. shows the average weekly output of the plant and the average weekly output of each size of furnace for the last five years.

TABLE XIV.—*Steel Production of Cleveland South Plant.*

Period.	Average Weekly Output of Shop. Tons.	Average Weekly Output per Furnace.		
		230-Ton Furnace. Tons.	140-Ton Furnace. Tons.	75-Ton Furnaces. Tons.
Year ending 30/9/1932 . .	3064	1973		1038
1933 . .	3851	Off	Built	961
1934 . .	4895	1906	Apr.	1024
1935 . .	4661	Off	1937	1023
1936 . .	7072	1684		1031
Six months ending 31/3/1937 .	7407	1632	1491*	1015

* First five weeks' operation of reconstructed furnace.

The tilting furnace has had periods of inactivity when tonnage requirements were not great. Its low output from the start of 1936 is due to the great increase in the total tonnage made in the shop, and a corresponding decrease in the service available.

During nine months of 1933 all the steel was made in fixed furnaces working on direct metal.

The record outputs are: The shop has made 8791 tons; the 230-ton tilting furnace, 2407 tons; the 75-ton fixed furnace, 1325 tons; and the newly-started 140-ton furnace, 1655 tons per week.

(7) *Steelmaking Practice.*

After a charge is tapped, the bottom is tried, and if in order, is quickly dried up. Any bad holes in the banks are filled up, and the gas is eased back while the remainder of the fettling is being completed. The tap-hole is closed, and charging is started with about half the total amount of steel scrap, followed immediately by the whole of the limestone and the ore. In amount these are usually about 6–7 tons of limestone and 10–15 tons of Swedish ore. Then the remainder of the steel scrap is charged, and any broken metal scrap or pig iron that may be needed. Provided that the charging has been reasonably fast, the whole is allowed to warm up for about half an hour, when the mixer metal, 50–60 tons, is added. This takes about 2½ hr. from tapping. There is usually a good reaction and the slag rises in the bath, but it is not allowed to run off during the first hour, after which 5–6 tons are run off before the charge settles down. When the charge is settled down but not properly melted, a little more slag may be run off, or the existing slag built up with lime, with the object of having a good basic slag by the time the charge is properly melted. The melting sample is then

drawn, and the charge is fed and worked in the ordinary way. It is sometimes necessary to take off more slag when the carbon has been brought down reasonably near to the required amount. When working a high-carbon charge there is seldom any difficulty in retaining the carbon while the sulphur and phosphorus are being removed, and as soon as the carbon is within 0·02% of the content required before tapping and the slag is of satisfactory analysis and physical condition, a series of three or four samples is drawn at five-minute intervals and tested for carbon and manganese. On the result of the first of these samples being returned, about 12 cwt. of lump ferro-manganese are added to the bath, and the charge is tapped when the result of the third sample is received. The final adjustment of the carbon, manganese and silicon is made in the ladle.

Manganese additions are made in the bath in the majority of charges from this plant, and occasionally silico-spiegel is used. In the case of very low-carbon steels, where ferro-manganese additions would tend to raise the carbon content above the specified limit, refined manganese and silico-manganese are added in the ladle. The average burden of the furnaces is shown in Table XV., and the working of a typical charge in Table XVI.

TABLE XV.—*Consumption of Materials in Hundredweights per Ton of Product.*

Mixer.			
Molten metal	19·76	Limestone	0·40
Cold pig	0·02	Ore	0·51
Steel scrap	0·08	Dolomite	0·10
Old moulds, &c.	0·01		
Skulls, &c.	0·13		
Steel Furnaces.			
Mixer metal	15·33	Lime	1·37
Direct metal	0·23	Limestone	1·02
Cold pig	0·20	Fluorspar	0·23
Old moulds, &c.	0·41	Dolomite	0·76
Steel scrap	3·12	Ferro-manganese	0·21
Skulls, &c.	0·83	Ferro-silicon	0·03
Mill scale	0·62	Ferro-chrome	0·01
Ores	4·22	Silico-manganese, spiegel, &c.	0·01

(8) *Casting Pit Practice.*

The ladles are nominally of 75 tons capacity and will hold 78–80 tons. They are lined with 4½ in. of Durham firebrick with a safety lining of 1½ in. of split. All casting is done from ladle stands; thus, having set the full ladle in a stand, the casting crane is free for other work. The steel is top-poured through 1½-in. clay nozzles; there are two stoppers in each ladle and two moulds to

TABLE XVI.—*Working of a Typical Charge in a 75-Ton Furnace.*

Charge No. 2661; June 15, 1937.

P.M.		P.M.	
2.40.	Tapped.	10.30.	10 cwt. fluorspar and 14 cwt. scale.
2.50.	Bottom tested.	10.45.	6 tons slag off.
3.03.	Bottom dried up.	10.50.	24 cwt. burnt lime and 14 cwt. scale.
3.05.	Ordinary fettling started.	11.00.	Sample: C 0·69%, S 0·066%, P 0·039%.
3.25.	Fettling finished.	11.30.	12 cwt. burnt lime and 7 cwt. scale.
3.30.	Commenced charging.	11.55.	Sample: C 0·52%, S 0·051%, P 0·036%.
3.45.	12 tons scrap charged.	A.M.	
4.20.	6½ tons limestone and 10½ tons of ore charged.	12.10.	5 cwt. burnt lime.
4.25.	5 tons scrap and 5 tons metal charged. All cold material now charged.	12.35.	5 cwt. burnt lime. Sample: C 0·38%, S 0·046%, P 0·036%, Mn 0·12%.
5.00.	56½ tons mixer metal; analysis: Si 0·60%, S 0·066%.	12.40.	Sample: C 0·36% (slag 7·8% Fe), Mn 0·11%.
6.35.	4 tons slag run off.	12.45.	Sample: C 0·36%, Mn 0·11%.
8.25.	12 cwt. burnt lime.	12.55.	Tapped.
8.35.	Sample: C 1·48%, S 0·075%, P 0·234%.		
8.40.	12 cwt. burnt lime and 28 cwt. scale.		
9.50.	12 cwt. burnt lime and 14 cwt. scale.		

Analyses.

	C. %.	Si. %.	S. %.	P. %.	Mn. %.
Pit sample	0·475	0·12	0·044	0·029	1·07
Ordered . .	0·48–0·51	0·12	0·040	0·040	1·03–1·08

a casting car. Practically the whole of the steel is teemed into wide-end-up fluted moulds. One range of ingots weighing from 3 tons 4 cwt. to 3 tons 15 cwt. is obtained from a mould 24 in. × 24 in. at the wide end and 76 in. high, and another range of ingots weighing from 4 tons to 4 tons 10 cwt. from a mould 26½ in. × 26½ in. × 75 in. high. The ingots are stripped by means of lugs set in the top of the ingot. About 12% of the steel that is made is cast with C. & D. hot tops. Every effort is made to have the moulds cool, about hand warm, before teeming, and the mould surface is either tar-sprayed or smoked with a piece of pitch. The average life of the moulds is 62 heats.

(9) *Fuel.*

In general, the fuel at present used in the plant is three-gas for the furnaces and coke-oven and blast-furnace gas on the mixer.

Gas Machines.—The gas plant consists of two banks of 3-ton Morgan machines, three in one bank and two in the other. The gas is produced from a mixture of Durham and Yorkshire coal of the

following analysis: Moisture, 2·53%; volatile matter, 31·93%; ash, 4·00%; sulphur, 1·15%; fixed carbon, 60·39%. The machines have 95 sq. ft. of hearth area inside the 4½-in. firebrick lining, and each has two water-cooled levellers. Coal is delivered from 15-ton bunkers to the hoppers over the mechanical feed; the ashes are discharged by a plough into a pit, from which they are removed by a grab carried on an overhead telpher car and delivered to wagons. The producers are blown by steam jet, giving a saturation temperature of about 53° C. The depth of the fuel bed is 18–20 in. on an ash bed of 20–22 in. The gas is delivered by each bank of producers into its own dust-catcher, which is amply provided with hoppers and slides, and from there it is led to a common main. The temperature of the gas leaving the producers is 700° C. The pressure in the main is maintained by an Arca regulator, normally set at 1·6 in. at the beginning of the week, and being increased to a maximum of 2 in. towards the end of the week. From the gas main, cross tubes lead the gas to each furnace, passing by way of a mushroom regulating valve to the drum reversing valve. The whole of the gas mains and cross mains are insulated with a 4½-in. course of insulating brick. The producer gas has the following average analysis: CO_2, 47·%; CO, 26·6%; CH_4, 2·7%; H_2, 13·2%; N_2, 52·8%; it has a tar content of 2·64 grains per cu. ft., and a moisture content of 17·6 grains per cu. ft.

The Three-Gas Mixture.—The blast-furnace and coke-oven gases are mixed at a point some 200 yards away from the plant, the volumetric ratio of the mixture being maintained constant by an Askania regulator actuated by the differential pressure across orifices in each of the mains. The mixed blast-furnace and coke-oven gases are added to the producer gas at each individual furnace, the mixture of the cold gas being fed into the hot producer gas after the furnace regulating valve, but before the drum reversing valve. An orifice which indicates the volume of mixed coke-oven/blast-furnace gas is installed in the main before it joins the producer-gas main, and thus the melter has an indication of the volume passing. The calorific value of the blast-furnace/coke-oven gas mixture is 250 B.Th.U. per cu. ft., but to a certain extent the actual proportions of producer gas and mixed blast-furnace and coke-oven gas used is left to the discretion of the melter.

Fuel Consumption.—The total fuel consumption, expressed as coal, over the six-months period ending January 2, 1937, including the mixer and all lighting-up fuel, is 4·61 cwt. per ton. Deducting the mixer figure of 0·58 cwt., the consumption on the furnaces, including lighting up, is 4·03 cwt. per ton.

V.—*Redcar.*

(1) *History.*

The erection of this plant was started and finished during the war, the first cast of steel being tapped in February, 1917. A full

description of the layout of the plant was given in the technical press in 1920.[3] The plant then consisted of a 400-ton mixer, four 60–70-ton fixed furnaces and three 80-ton tilting furnaces, and the output in 1925 was 1050–1200 tons per week.[2] Very little alteration has been made in the general construction of the plant, but most of the furnaces have been altered. The plant now consists, in addition to the mixer, of four 80-ton fixed furnaces, five 85-ton fixed furnaces and one 85-ton tilting furnace.

(2) *Outline of Purpose and Capacity.*

The plant has a present maximum output of 8865 tons, but a very valuable feature is that it can and does run at an average make of over 8000 tons a week with seven furnaces working. The greater part of this steel is in ingots of 7–10 tons weight for plates. This plant is the one, as will be seen from a comparison of the average burdens, that works the most steel scrap. For many years now the percentage of steel scrap charged into the furnaces has not fallen below 33%. Since the plant is also served with good-quality basic iron, it means that the slag volume is low in comparison with that of the other fixed-furnace plants, and there is a correspondingly shorter working time. There was a period during the trade depression when the blast-furnace plant was idle, when the steel plant worked on cold-metal practice, with an average of about 50% scrap. This period is indicated in the data of the average outputs for the last five years.

(3) *Layout of Plant.*

A plan of the melting shop is shown in Fig. 18, and a cross-section in Fig. 19. The four main bays are all 1015 ft. long.

The stock bay is 90 ft. wide and is served by four fast 10-ton magnet cranes. These cranes have chains suspended from above the magnet so that three charging boxes can be lifted simultaneously and placed on the charging bench, which is mounted on the furnace stage the full length of the shop and projects under the hoist of the stock-bay cranes. All materials for the furnaces are placed in this bay and are loaded direct into the charging boxes. The scrap destined for each furnace stands immediately opposite to it.

The furnace bay is 62 ft. wide and is served by three 5-ton revolving overhead charging cranes, and one 40-ton overhead crane, situated between two of the chargers, that puts hot metal into the mixer and does general lifting work about the plant. The mixer is in the middle of the line of furnaces; on one side of it are four 80-ton fixed furnaces and the 85-ton tilting furnace, and on the other side five 85-ton fixed furnaces.

The casting bay is 65 ft. wide and is equipped with three 120-ton casting cranes, each with two 15-ton auxiliary hoists mounted one on each side of the main hoist. Three railroads run the length of

the bay, the one nearer the furnaces being used for ladles for tapping slag; the other two are principally used for the shunting and setting of the rakes of casting cars at the teeming platforms extending the full length of the bay.

The gas-producer bay houses the static water-bottom producers, the eleven waste-heat boilers and the dolomite mill and storage bunkers.

The stripper bay is placed in line between the casting bay and the mill soaking bay; the full moulds move forward from the teeming stage to the stripper, and, being stripped, the ingots go straight through to the soakers. The building is 150 ft. long by 50 ft. wide and is served by a 10-ton stripper crane. The bay has storage capacity for ingot moulds; and the stripping, setting and marshalling of rakes is done on three railroads that run through it.

(4) *Mixer.*

The 400-ton active mixer is on conventional lines, being hydraulically operated, with movable port ends and water-cooled ports. The bath is 46 ft. in length by 18 ft. wide and 5 ft. deep. The bottom is of rammed dolomite on magnesite. The regenerator system is of ordinary design, suitably proportioned.

It is fired with a mixture of coke-oven and producer gas. A fixed amount of coke-oven gas is passed to the furnace, and the amount of producer gas is varied to suit altering requirements. The mixer has its own producers isolated to it, and only one producer is worked unless a large amount of cold material is charged, when a second producer is brought in. The coke-oven gas enters the furnace through the gas port, passing down a long water-cooled tube which extends to the face of the block.

Metal from the blast-furnace plant is delivered in 30-ton ladles at intervals of 2 hr., about 60 tons per cast. This is lifted by the 40-ton ladle crane and poured into the mixer through a movable metal chute, which is placed in position by the charger at the charging side of the furnace. Metal for the steel furnaces is taken off from the tapping side into 55-ton ladles mounted on a low bogie which stands on the weighbridge, the weight being recorded, as the ladle is filled, on the beam placed on the furnace stage. When full the ladle is drawn from under the furnace, and is taken to the steel furnace by one of the casting cranes.

The mixer is worked as actively as possible; the analysis aimed at is 0·50% of silicon with sulphur as low as possible. Limestone and ore are charged, the amount of these depending on the quality and quantity of both the hot and the cold material charged. An average of 750 tons a week of cold material is charged. This mixer disposes of most of the old ingot moulds, miscellaneous iron scrap and skulls, in addition to about 430 tons of pig iron a week. The burden as an average of three months is shown in Table XVIII.;

the following figures show the amount of refining done in the mixer :

	C. %.	Si. %.	S. %.	P. %.	Mn. %.
Metal entering mixer . .	3·92	1·06	0·046	1·41	1·15
Metal leaving mixer . .	3·79	0·58	0·039	1·22	0·85

The fuel consumption is : Coal, 0·33 cwt. per ton ; gas (calculated to coal equivalent), 0·32 cwt. per ton ; total consumption, 0·65 cwt. per ton of ingots.

(5) *Steel Furnaces.*

The four 80-ton furnaces and two of the 85-ton furnaces are essentially similar. Their principal dimensions are given in Table XX. The bottom, with the exception of the firebrick lining the pan, is entirely of magnesite, the minimum thickness of which is 9 in., and which is carried up the linings to 9 in. above the fore-plate level. All bottoms are fritted-in with dolomite. The back and front linings are both vertical and 18 in. thick. The front lining is of silica, and the back, with the exception of the silica hot-metal door, is of metalcase magnesite. Each furnace has five doors on the charging side ; two of these in the 80-ton and three in the 85-ton furnace are charging doors. The roof and ramps are of silica, 12 in. thick. There is no water-cooling whatever on these six furnaces. The doors are pneumatically operated by cylinders mounted at the ends of the furnace.

Another 85-ton furnace is similar in general construction to the above, but has Moody ports and water-cooled door frames.

The remaining 85-ton fixed furnace was recently reconstructed. A longitudinal section of it is shown in Fig. 20, and its dimensions are given in Table XX. It has a very shallow bath, with a magnesite bottom with dolomite fritted on. It has a sloping back wall, lined with 18-in. of metalcase magnesite, with a door at each end. The front lining is vertical, with five doors, the three inner ones, which are the charging doors, having water-cooled frames. The 12-in. silica roof rises from the ends towards the middle. The doors are operated hydraulically.

The 85-ton tilting furnace is operated hydraulically and has water-cooled movable port blocks. It is built on conventional tilting-furnace lines ; it has rather a deep bath, short ports, and a sloping magnesite back wall.

The furnaces are fired with mixed coke-oven and producer gas, the coke-oven gas being admitted to the producer-gas main before the drum valve. A separate control valve for the coke-oven gas is on the furnace stage, the volume used being indicated to the melter by a pressure gauge.

The producer gas is regulated by a dry mushroom valve, and reversed by a pneumatically operated drum valve. The air supply is naturally drawn, and air reversal is done by a butterfly valve.

The furnaces work with about 1·2 in. W.G. draught in the boiler inlet flue. The waste gas analysis averages 11% of CO_2 and 2% of oxygen.

(6) *Outputs and Products.*

Most of the steel made is rolled into plates. About 2% is alloy constructional, 2% high-manganese, 6% under 0·10% carbon, and the remainder 0·10–0·23% carbon steel. Table XVII. shows the average weekly output of the plant and the average weekly output of each size of furnace for the last five years.

TABLE XVII.—*Steel Production of Redcar Plant.*

Period.	Average Weekly Output of Plant. Tons.	Average Weekly Output per Furnace.		
		85-Ton Tilter. Tons.	80-Ton Fixed. Tons.	85-Ton Fixed. Tons.
Year ending 30/9/1932 . .	2655	...	790	917
1933 . .	3468	...	881	921
1934 . .	5089	...	1072	1112
1935 . .	5952	...	1184	1276
1936 . .	7668	1074	1142	1255
Six months ending 31/3/1937 .	8287	1082	1141	1298

During the period August, 1931, to January, 1934, the furnaces worked scrap and cold pig.

The record outputs are: Shop, 8865 tons per week; furnace record 1486 tons, made by the newly reconstructed 85-ton fixed furnace.

(7) *Steelmaking Practice.*

After a furnace has been tapped, any holes in the bottom are splashed out, the bottom is dried up and the tap-hole is closed. The bottom and banks are then fettled as usual. Fettling completed, the bottom is warmed and charging is started. About one-third of the scrap is spread as evenly as possible over the bottom, warmed if thought necessary, and the ore and limestone are charged. This is followed by the remainder of the scrap, and when this is warm enough the mixer metal is added to complete the charge. If the scrap is reasonably heavy the time taken in charging is about three hours.

Almost immediately following the addition of the metal a reaction starts, the slag rises in the bath, and a portion of it is allowed to run off. When the reaction commences to subside, the slag notch is closed, and the melting of the scrap proceeds quickly. When the charge is melted, a sample is drawn and the carbon judged. Ore is fed if necessary until the carbon content is low

enough, leaving a reasonable working margin above the carbon required in the finished steel. The slag is now built up with burnt lime, scale and fluorspar, the aim being to get a limey slag that will boil vigorously. When this condition has been reached, a sample is sent for analysis. Normally no trouble whatever is experienced with sulphur or phosphorus, and when both are down to the required limits, the bath, if necessary, is steadied by a few pieces of pig. While the tapping sample is being analysed, about half the required ferro-manganese is added to the bath. The balance of the additions are made to the ladle.

The burden, as an average of three months, is shown in Table XVIII., and the working of a typical charge is shown in Table XIX.

TABLE XVIII.—*Consumption of Materials in Hundredweights per Ton of Product.*

Mixer.			
Molten metal	16·99	Limestone	0·46
Cold pig	1·77	Ore	0·40
Steel scrap	...	Dolomite	0·04
Old moulds, &c.	0·66		
Skulls, &c.	0·58		
Steel Furnaces.			
Mixer metal	11·87	Lime	0·79
Direct metal	0·14	Limestone	1·15
Cold pig	0·76	Fluorspar	0·17
Old moulds, &c.	0·02	Dolomite	0·78
Steel scrap	6·86	Ferro-manganese	0·15
Skulls, &c.	0·28	Ferro-silicon	0·03
Mill scale	0·31	Silico-manganese	0·01
Ores	3·08		

(8) *Casting-Pit Practice.*

The steel ladles are of 80 and 90 tons capacity, lined with Durham firebrick. The ladle is held by the casting crane during tapping and teeming. All steel is top-poured through a single stopper. Soft steels are teemed through a $1\frac{1}{4}$-in. fireclay nozzle, hard steels through $1\frac{1}{4}$-in. clay with a $1\frac{5}{8}$-in. magnesite ring. Moulds to be used for high-carbon or high-manganese steels are provided with deep splash cans and treated with fuel oil. The average mould lives are: 10-ton, 90; 7-ton, 97; 5-ton, 61; $3\frac{1}{2}$-ton, 66; 34-cwt., 75. A copper mould stool now in use has a life to date of 985 heats. There is very little sign of cutting, only three shallow holes $\frac{3}{8}$–$\frac{1}{2}$ in. in depth; so far, only one side of it has been used.

(9) *Fuel.*

Three static water-bottom producers are isolated to each furnace, two being worked and one kept as a stand-by. The producers have

a hearth area of 95 sq. ft.; the normal gasification rate is 9 cwt. per hr., the maximum 12 cwt. The coal is chiefly Durham double nuts of the following average analysis: H_2O, 2·82%; ash, 3·92%; volatile matter, 33·68%; sulphur, 1·14%; fixed carbon, 62·4%. They are hand-fed from overhead bunkers, hand-poked and hand-cleaned every 24 hr. The ashes when removed are loaded into wagons by an ash hoist. The producers are blown by steam jet, the saturation temperature being 50° C., through a fuel bed 23 in. thick, the rate of driving being manually controlled to maintain the gas pressure constant. The desirable pressure varies from 1·8

TABLE XIX.—*Working of a Typical Charge in an 80-Ton Fixed Furnace.*

Charge No. 329; June 18, 1937.

A.M.		P.M.	
7.00.	Furnace tapped.	1.25.	Sample drawn and judged.
7.15.	Bottom dried up.	1.30.	20 cwt. Swedish ore fed.
7.20.	Tap-hole closed. Fettling.	2.10.	Sample: C 0·70%, S 0·051%.
7.55.	Warming bottom.	2.15.	20 cwt. Swedish ore.
8.00.	Commenced charging.	2.30.	40 cwt. burnt lime, 8 cwt. fluorspar charged.
8.15.	9 tons scrap charged.	3.00.	Sample: C 0·35%, S 0·044%, P 0·25%.
9.00.	9 tons ore and 5 tons limestone charged, followed by further 19 tons scrap and 2 tons pig iron.	3.05.	20 cwt. scale charged.
10.45.	53 tons mixer metal charged; analysis: Si 0·47%, S 0·039%.	3.10.	Slagging, 1 ton run off.
11.00.	Slagging.	3.25.	Sample: C 0·26%, Mn 0·14%, P 0·05%.
11.30.	About 3 tons slag off.	3.26.	20 cwt. burnt lime charged.
		3.46.	Sample: C 0·19%, P 0·04%.
		3.50.	Tapped.

Weight of ingots, 80 tons 12 cwt.

Pit Sample Analysis.

C. %.	Si. %.	S. %.	P. %.	Mn. %.
0·21	0·034	0·031	0·036	0·46

to 2·0 in. W.G. The gas has the following average analysis: CO_2, 6·73%; CO, 23·47%; CH_4, 3·18%; H_2, 12·35%; N_2, 54·27%. The tar content is 2·85 grains per cu. ft. and the moisture 29·3 grains per cu. ft. It enters the main at an average temperature of 725° C., and then passes by a downcomer to a flue passing underneath the stock bay to the gas valve, where it is joined by the coke-oven gas.

Fuel Consumption.—The total fuel consumption, expressed as coal, over the six months' period ending January 2, 1937, including the mixer and all lighting-up fuel is 4·21 cwt. per ton. Deducting the mixer figure of 0·65 cwt., the consumption on the furnaces, including lighting up, is 3·56 cwt. per ton, excluding lighting up 3·49 cwt. per ton of ingots.

General Observations.

Materials.

It is nowadays taken for granted that the basic open-hearth is an accommodating process; so it is, in the sense that, given time, it will make good steel out of any ferrous materials supplied to it; but in a survey of that restricted part of the basic process that forms hot-metal practice, it cannot be too strongly stressed that for successful economic operation the supply of steelmaking materials, in regard to both quality and quantity, must be as closely and carefully controlled as possible. Naturally, this observation applies more particularly to the molten metal from the blast-furnaces, since, even with a mixer that will melt a considerable amount of cold material, it forms the larger part of the burden.

If the metal from the blast-furnace is such a vital factor in the successful operation of the hot-metal process, so, naturally, is the practice in the mixer, where one is used, and in this connection the mixer practice developed at Acklam and introduced at Britannia when the plant restarted may be of interest. The principle of the practice is to charge into the mixer a proportion of whatever steel scrap is available. It has been argued that the practice is wrong, that all steel scrap should go into the steel furnace where it just needs melting, and that it is a retrograde step to turn finished steel into iron and pay a second conversion cost on it. Actually, when working the hot-metal process, the steel scrap charged into the furnace does not usually just need melting; even there it becomes carburised to a certain extent. The advantage of the practice is both mechanical and metallurgical. A steel furnace must be charged at a certain definite time, and particularly with large tilting furnaces with a high capacity/charging-facility ratio, the less scrap there is to go in, above a certain reasonable amount, the better. Some charging can usually be done in the mixer during the time when the furnaces are not using the chargers, and this time can be used for charging the light awkward scrap, leaving the more manageable scrap to go into the furnace.

That is the mechanical aspect; the metallurgical is at least as important. The practice presupposes that the iron as it comes from the blast-furnace does not require too much refining to bring its silicon content down to about 0·40%. Given this condition, no ore need be charged into the mixer; and the iron as it comes out is always in good physical condition. When a mixer has to be heavily charged with cold materials, and must also be frequently drawn from, if the cold chargings are all iron they will run out of the tap-hole at a low temperature, causing excessive ladle skulls and sticky working in the steel furnace. If, on the other hand, as much of the cold charging as possible is steel, it will not run at the low temperature but will stay until it is melted, and the condition of the metal will be good. A similar argument applies to feeding

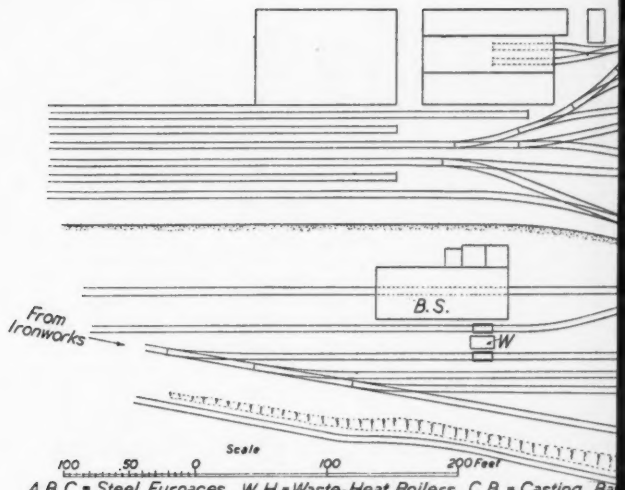

From Ironworks
B.S.
W
Scale
100 50 0 100 200 Feet
A.B.C. = Steel Furnaces. W.H. = Waste-Heat Boilers. C.B. = Casting Ba
M. = Mixer. S.B. = Stocking Bay. L. = Laboratory.
G.P. = Gas Producers. C.S. = Charging Stage. S.S. = Stripper Sh

FIG. 1.—Plan

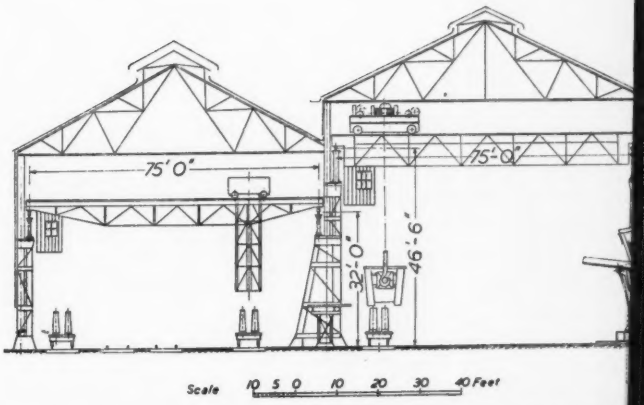
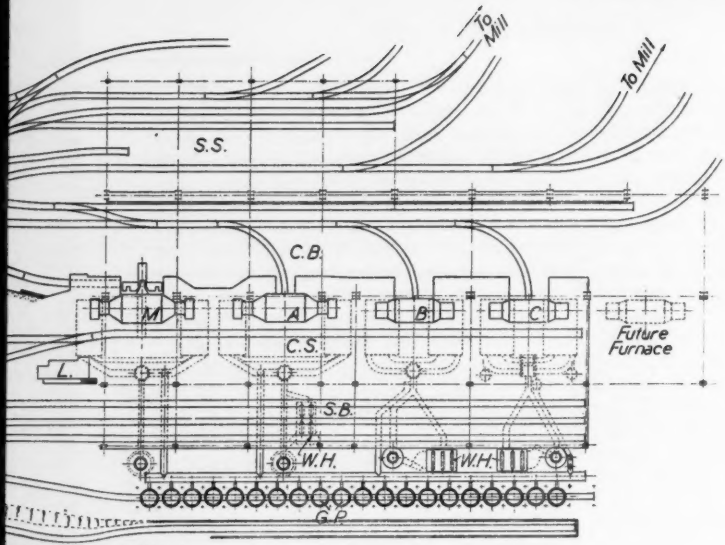
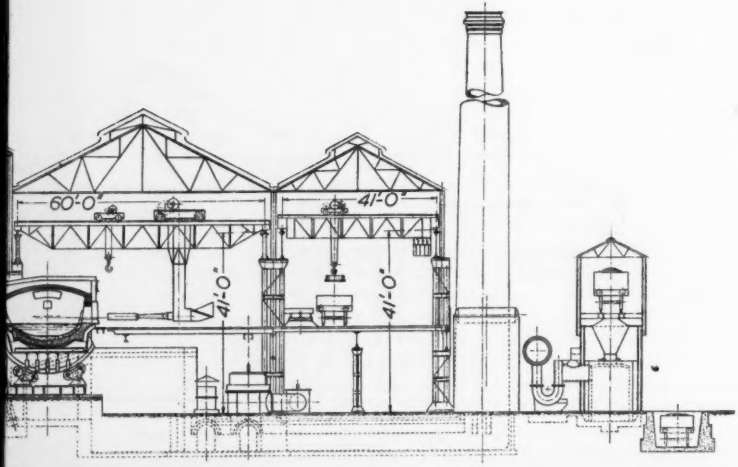


FIG. 2.—Cross-S



W. = Metal Weigh.
op. B.S. = Brick Store.

of Acklam Melting Shop.



tion of Acklam Melting Shop.

[Geary.

[To face p. 272 P.

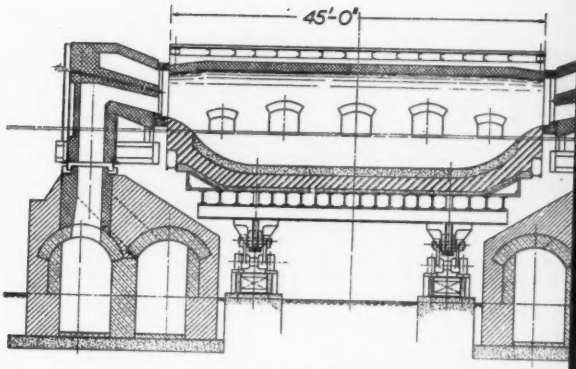


FIG. 3.—Longitudinal Section of *B* Furnace, Acklam Melti

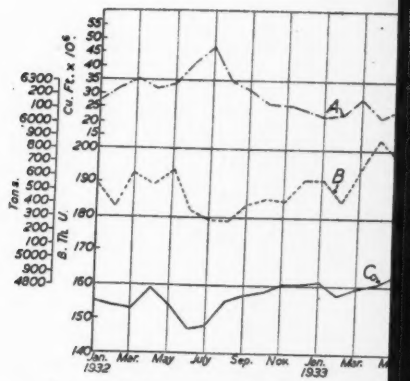
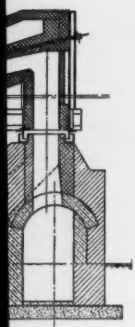


FIG. 5.—Influence on Output of Decrea



g Shop.

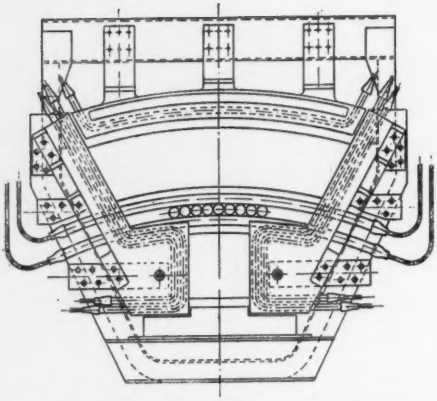
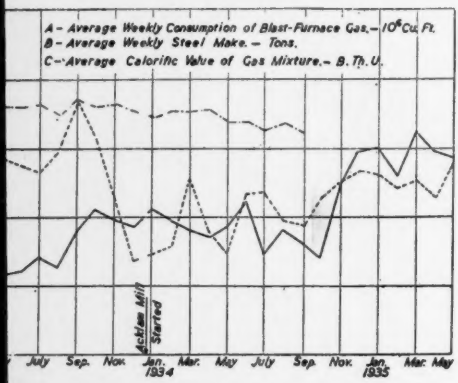


FIG. 4.—Arrangement of Water-Cooled Castings on Port Block of Tilting Furnaces.



ng Proportion of Blast-Furnace Gas in Mixture.

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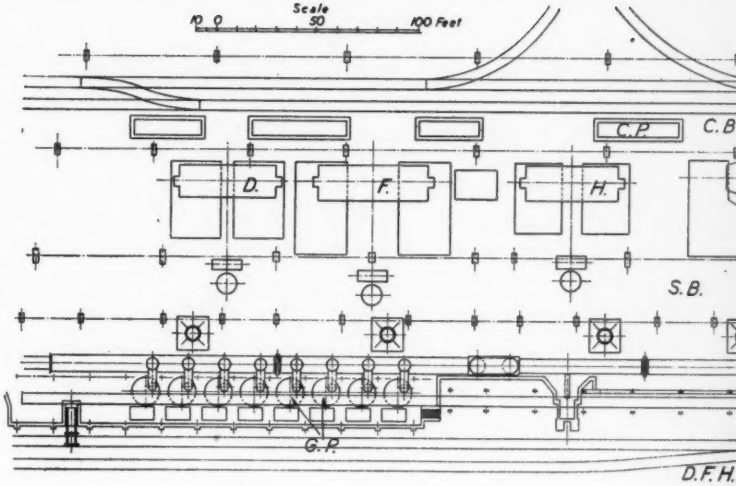


FIG. 6.—Plan of B

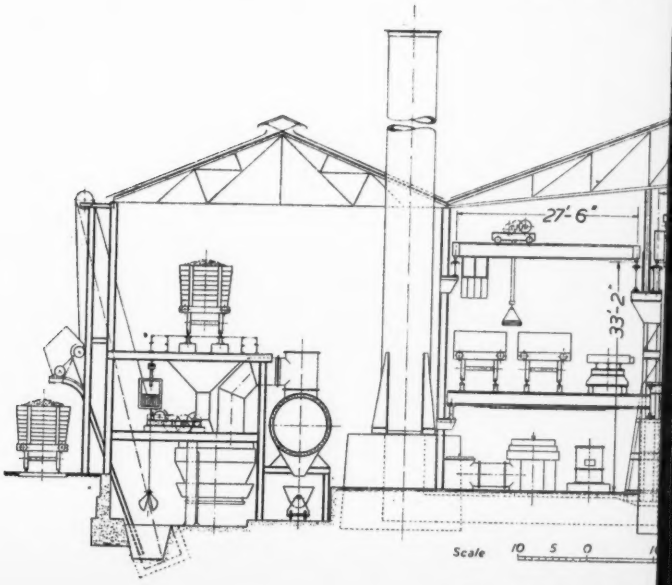
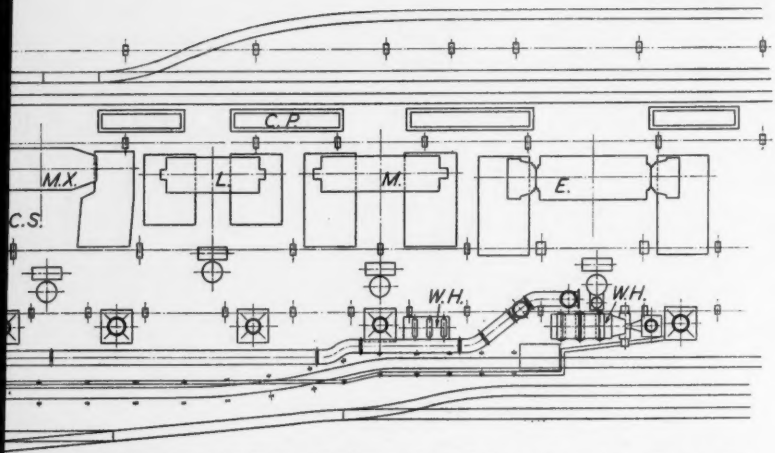
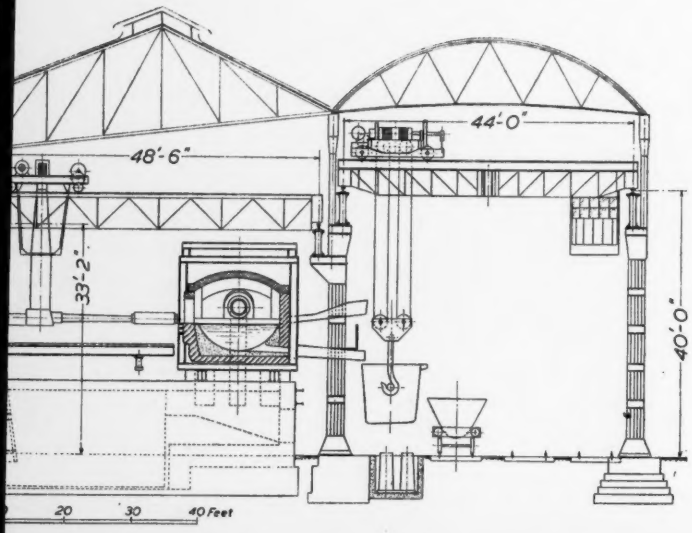


FIG. 7.—Cross-Section



M.E. = Steel Furnaces. G.P. = Gas Producers. S.B. = Stocking Bay. C.B. = Casting Bay.
M.X. = Mixer. W.H. = Waste-Heat Boilers. C.S. = Charging Stage. C.P. = Casting Pits.

itannia Melting Shop.



of Britannia Melting Shop.

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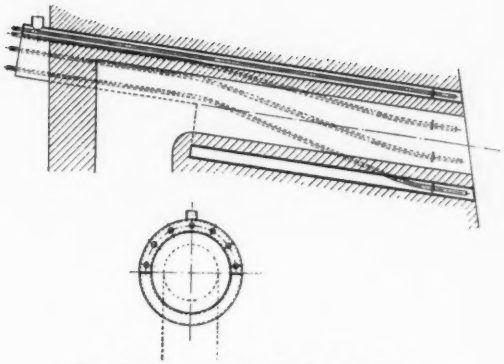


FIG. 8.—Moody Water-Cooled Gas Port.

O.P.R.S.T.U. = Steel Furnaces. C.B. = Casting Bay. C.O. = Coke-Oven Gas Main. P.
M. = Mixers. C.P. = Casting Platforms. G.B. = Coke-Oven Gas Boosters. O
C.S. = Charging Stage. S.S. = Stripper Shop. G.P. = Gas Producers.

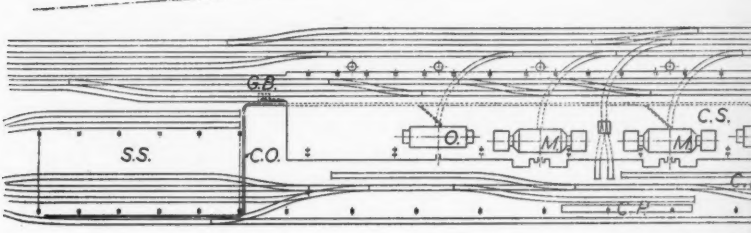


FIG. 9.—Plan of Clevela

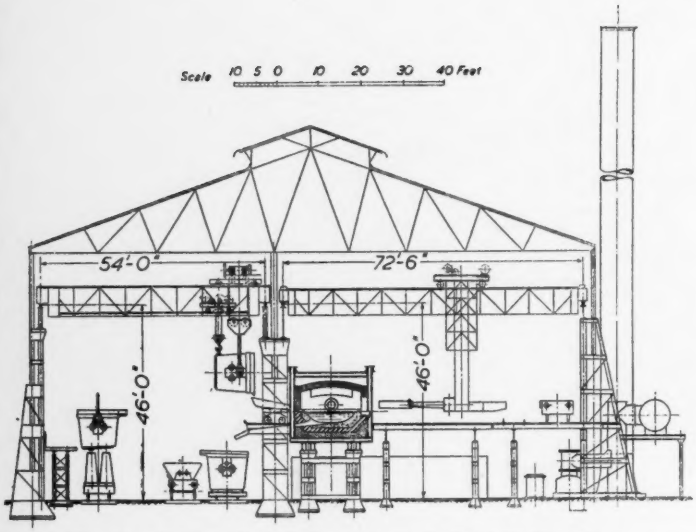
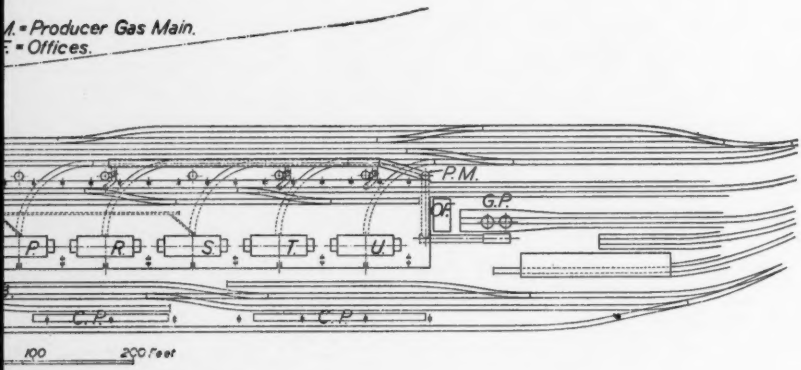


FIG. 10.—Cross-Section of Cleveland North Plant Melting Shop.



d North Plant Melting Shop.

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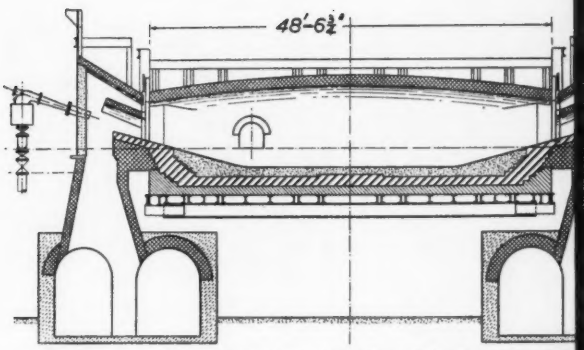

FIG. 11.—Longitudinal Section of 100-Ton Coke-Oven-Gas-Fir

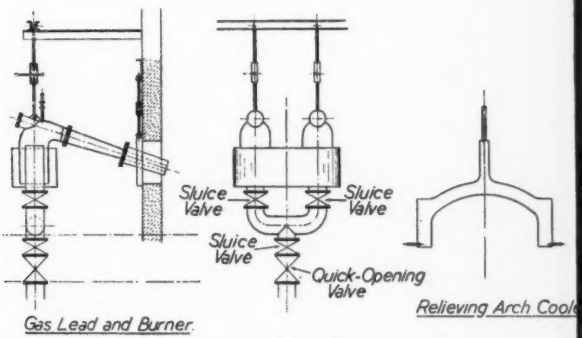

FIG. 13

d Furnace.

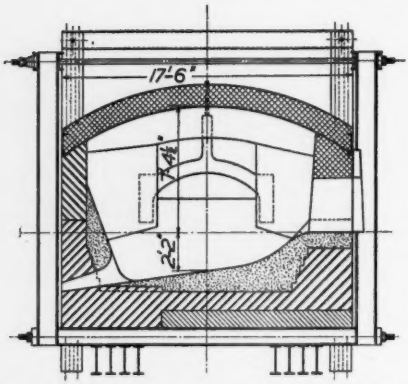

FIG. 12.—Cross-Section of 100-Ton Coke-Oven-Gas-Fired Furnace.

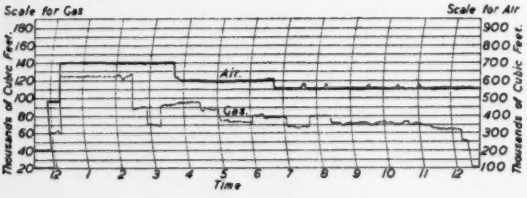

FIG. 14.—Gas and Air Consumptions during Charge Detailed in Table X.

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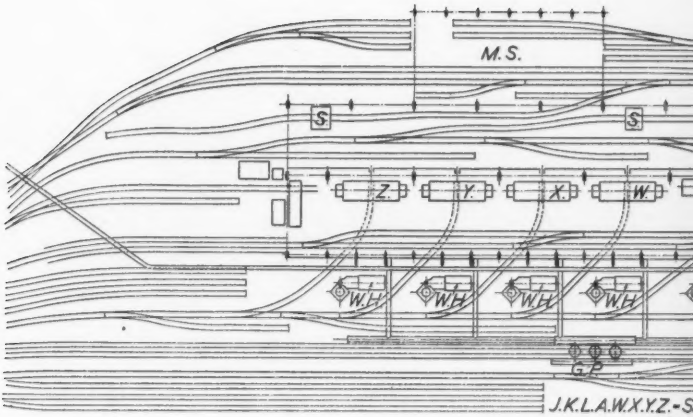


FIG. 15.—Plan of Clev

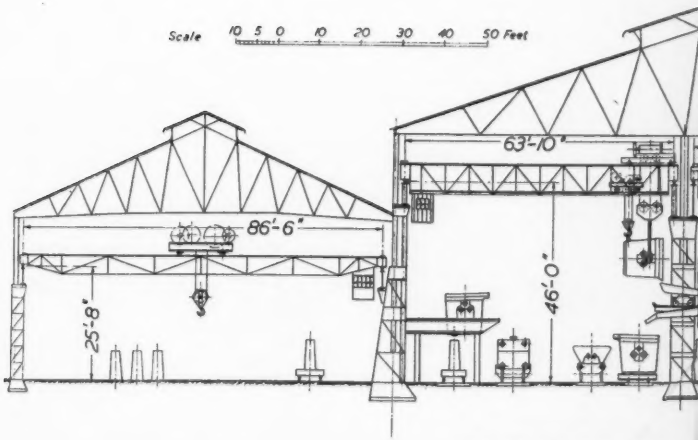
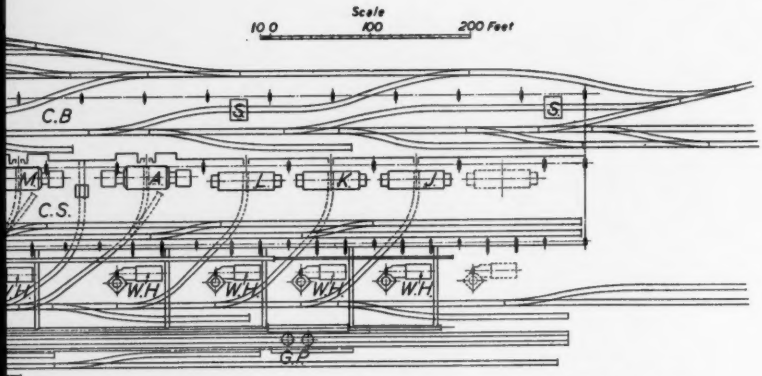
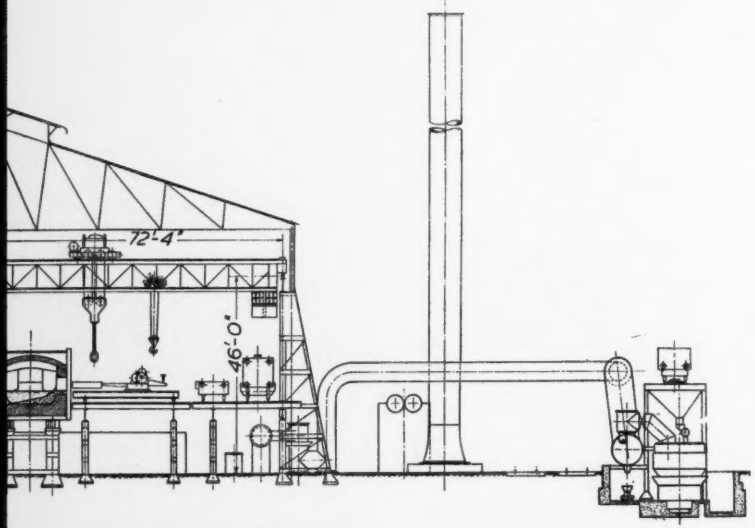


FIG. 16.—Cross-Section of C



l Furnaces. C.B. = Casting Bay. M.S. = Ingot Mould Shop. G.P. = Gas Producers.
er. S. = Casting Stand. W.H. = Waste-Heat Boilers. C.S. = Charging Stage.

nd South Plant Melting Shop.



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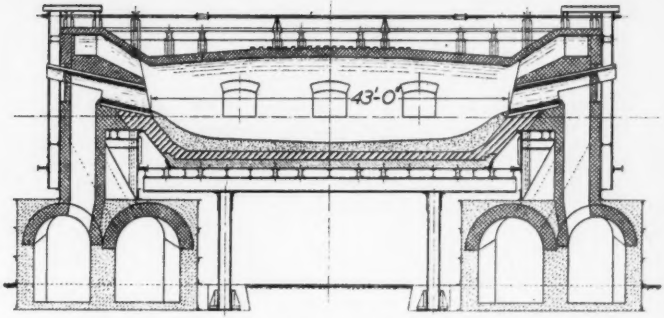


FIG. 17.—Longitudinal Section of 140-Ton Fixed Furnace.

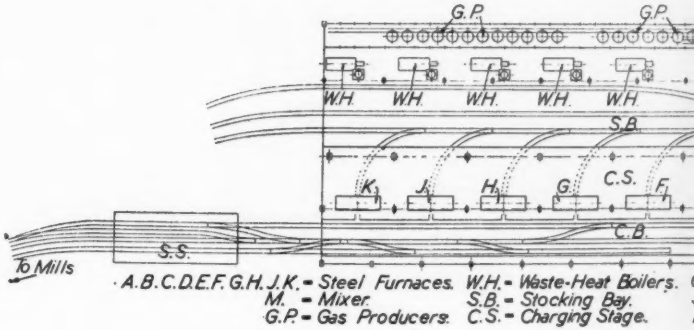


FIG. 18.—Plan

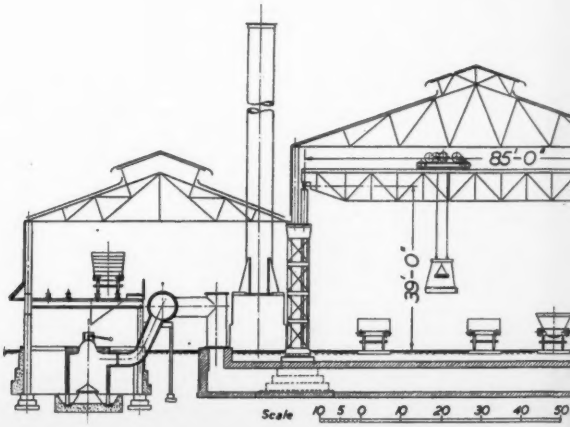


FIG. 19.—Cross-Sect

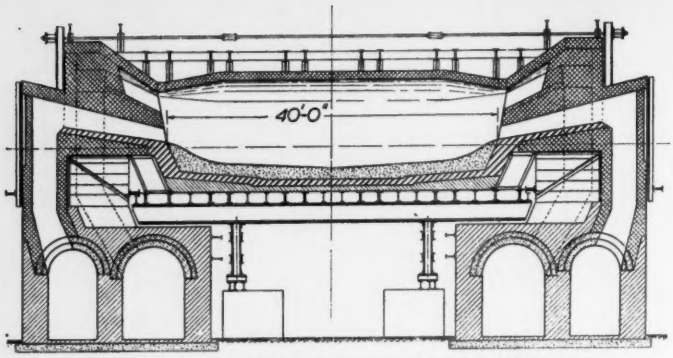
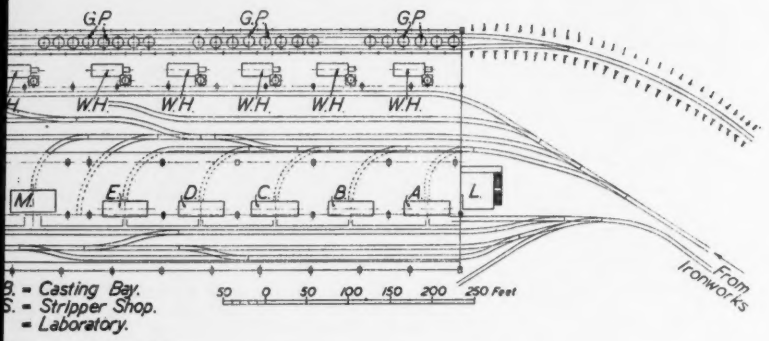
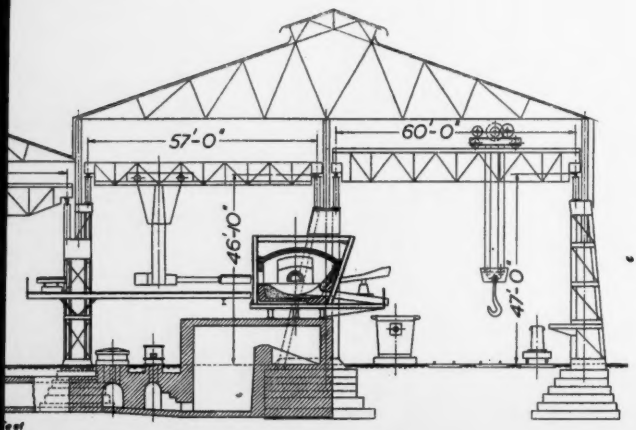


FIG. 20.—Longitudinal Section of 85-Ton Fixed Furnace.



Redcar Melting Shop.



on of Redcar Melting Shop.

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Details.		
		250-T
Hearth at foreplate level :	Length . . .	42
	Width	15
	Depth	3
	Area	600
		Gas.
Ports :	Area	3·50 sq. f
	Length	9 ft. 3 in.
	Pitch	$2\frac{3}{4}$ in 12
Uptakes :	Area	11·25 sq. f
	Length	20 ft. 0 in.
Regenerators :		
Length		19 ft. 2 in.
Width		6 ft. 0 in.
Height		12 ft. 9 in.
No. of courses		34
Vol. excluding bearer blocks. Cu. ft. . .		1,460
Vol. per sq. ft. of bath area. Cu. ft. . .		2·44
Vol. per ton of bath capacity. Cu. ft. . .		5·80
Effective heating surface. Sq. ft. . . .		5,610
Total area of vertical passages. Sq. ft. . .		51
Size of bricks. In.		9 × 4½ ×
Method of laying		←
Flues :		
Opening into regenerators. Sq. ft. . . .		15·0
Area of flue. Sq. ft.		17·5
Length to valves		53 ft. 0 in.
Depth below foreplate		32
Type of valves		Drum
Length from valve to boiler or chimney damper .		35 ft.
Boiler : Type		Babco
Heating surface		4,1
Fan : Type		
Rated capacity—Volume. Cu. ft. per min. .		5
Speed. R.p.m. . .		
B.h.p.		
Total suction. In. W.G. .		
Chimney : Height		160 ft.
Inside diameter		6 ft.
		6 ft.

ACKLAM.

		230-Ton Furnace. 37 ft. 3 in. 16 ft. 6 in. 3 ft. 9 in. 560 sq. ft.		230-Ton Furnace. 39 ft. 3 in. 16 ft. 6 in. 3 ft. 9 in. 590 sq. ft.		55-T 3 1 3 32
	Air.	Gas.	Air.	Gas.	Air.	Gas.
ft.	12·70 sq. ft.	2·7 sq. ft.	16·2 sq. ft.	2·7 sq. ft.	16·2 sq. ft.	3·14 sq. f
.	9 ft. 3 in.	6 ft. 6 in.	6 ft. 6 in.	6 ft. 0 in.	6 ft. 0 in.	9 ft. 9 in
	$2\frac{3}{4}$ in 12	3 in 12	4 in 12	4 in 12	5 in 12	$1\frac{3}{4}$ in 12
ft.	22·5 sq. ft.	7·5 sq. ft.	15·0 sq. ft.	12·5 sq. ft.	25·0 sq. ft.	6·66 sq. f
.	19 ft. 6 in.	17 ft. 0 in.	25 ft. 6 in.	20 ft. 0 in.	27 ft. 0 in.	11 ft. 6 in
.	19 ft. 2 in.	22 ft. 0 in.	22 ft. 0 in.	22 ft. 0 in.	22 ft. 0 in.	17 ft. 6 in
.	8 ft. 0 in.	8 ft. 0 in.	10 ft. 0 in.	8 ft. 0 in.	10 ft. 0 in.	8 ft. 0 in
.	12 ft. 9 in.	12 ft. 9 in.	12 ft. 9 in.	12 ft. 9 in.	12 ft. 9 in.	10 ft. $1\frac{1}{2}$ i
	34	34	34	34	34	27
	1,940	2,240	2,800	2,240	2,800	1,420
	3·23	4·0	5·0	3·8	4·75	4·35
	7·8	9·7	12·2	9·7	12·2	25·8
	7,480	8,630	10,800	8,630	10,800	5,460
	68	78	98	78	98	62
3	9 × $4\frac{1}{2}$ × 3	9 × $4\frac{1}{2}$ × 3	9 × $4\frac{1}{2}$ × 3	9 × $4\frac{1}{2}$ × 3	9 × $4\frac{1}{2}$ × 3	9 × $4\frac{1}{2}$ ×
	20·6	26·2	33·2	26·2	33·2	21·7
	20·0	22·5	22·5	22·5	22·5	16·0
.	40 ft. 0 in.	39 ft. 0 in.	22 ft. 0 in.	39 ft. 0 in.	22 ft. 0 in.	40 ft. 0 in
ft.	0 in.	32 ft. 0 in.		32 ft. 0 in.		24 f
	42-in. B'fly	Drum	42-in. B'fly	Blaw-Knox		Drum
	...	36 ft.	...	36 ft.	...	36 ft.
ck & Wilcox		Stirling		Stirling		
28 sq. ft.		7,982 sq. ft.		7,982 sq. ft.		
	47 in.		47 in.		47 in.	
5,000		55,000		55,000		
735		735		735		
100		100		120		
$5\frac{7}{8}$		$4\frac{1}{2}$		6		
	161 ft. 6 in.		161 ft. 6 in.		161 ft. 6 in.	153
9 in. bottom		8 ft. 9 in. bottom		8 ft. 9 in. bottom		6
0 in. top		6 ft. 6 in. top		6 ft. 6 in. top		

TABLE XX.—*Dimensions o*

	BRITANNIA.						
	55-Ton Furnaces. 32 ft. 0 in. 12 ft. 0 in. 3 ft. 3 in. 326 sq. ft.		100-Ton Furnaces. 33 ft. 0 in. 12 ft. 9 in. 3 ft. 0 in. 358 sq. ft.		250-Ton Furnace. 46 ft. 9 in. 16 ft. 3 in. 3 ft. 7½ in. 692 sq. ft.		100
	Gas.	Air.	Gas.	Air.	Gas.	Air.	G
t.	3·14 sq. ft.	20·12 sq. ft.	5·24 sq. ft.	28·0 sq. ft.	4·0 sq. ft.	16·0 sq. ft.	2·4
n.	9 ft. 9 in.	10 ft. 0 in.	9 ft. 9 in.	5 ft. 6 in.	9 ft. 0 in.	8 ft. 0 in.	8 ft
	1¾ in 12	7 in 12	1¾ in 12	7½ in 12	2¾ in 12	4¼ in 12	2½ i
t.	6·66 sq. ft.	17·5 sq. ft.	9·68 sq. ft.	25·0 sq. ft.	10·0 sq. ft.	22·0 sq. ft.	8·2
n.	11 ft. 6 in.	20 ft. 6 in.	12 ft. 6 in.	13 ft. 0 in.	17 ft. 0 in.	16 ft. 0 in.	14 ft
n.	17 ft. 6 in.	17 ft. 6 in.	17 ft. 6 in.	17 ft. 6 in.	19 ft. 4 in.	19 ft. 4 in.	22 ft
n.	8 ft. 0 in.	10 ft. 0 in.	8 ft. 0 in.	10 ft. 0 in.	8 ft. 0 in.	10 ft. 0 in.	8 ft
n.	10 ft. 1½ in.	10 ft. 1½ in.	9 ft. 9 in.	9 ft. 9 in.	12 ft. 9 in.	12 ft. 9 in.	13 ft
	27	27	26	26	34	34	
	1,420	1,770	1,360	1,700	1,970	2,460	2,6
	4·35	5·40	3·80	4·75	2·84	3·54	
	25·8	32·1	13·6	17·0	7·9	9·8	
	5,460	6,830	5,250	6,560	7,580	9,470	10,0
	62	78	62	78	69	86	
3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 ×
	Straight through						
	21·7	27·7	21·7	27·7	21·7	27·7	3
	16·0	16·0	16·0	16·0	18·0	22·5	2
n.	40 ft. 0 in.	18 ft. 0 in.	36 ft. 0 in.	20 ft. 0 in.	56 ft. 0 in.	36 ft. 0 in.	56 f
	24 ft. 10 in.		25 ft. 9 in.		25 ft. 0 in.		
	Drum	42-in. B'fly	Drum	42-in. B'fly	Drum	48-in. B'fly	F
	36 ft.	...	12 ft.	...	16 ft.	...	1
	None		Stirling		Stirling		
			3,617 sq. ft.		10,700 sq. ft.		
	...		F 45 in. | M 47 in.		53½ in.		
	...		40,000 | 50,000		85,000		
	...		735		735		
	...		100		2 at 100		
	...		3¾		5½		
	153 ft.		153 ft.		177 ft.		
	6 ft. 0 in.		6 ft. 0 in.		6 ft. 0 in.		

of Steel Furnaces.

	Cleveland North Plant.				Cleveland	
	-Ton Producer Furnaces. 36 ft. 0 in. 13 ft. 0 in. 2 ft. 9 in. 400 sq. ft.		100-Ton Coke-Oven Furnaces. 42 ft. 0 in. 11 ft. 6 in. 2 ft. 2 in. 410 sq. ft.		75-Ton Furnaces. 32 ft. 0 in. 13 ft. 0 in. 2 ft. 9 in. 354 sq. ft.		140-To 39 f 12 f 3 f 430 s
	Gas.	Air.	Gas.	Air.	Gas.	Air.	Gas.
	sq. ft. . 9 in. in 12	16·6 sq. ft. 7 ft. 0 in. $5\frac{1}{2}$ in 12	... ...	... ...	2·1 sq. ft. 11 ft. 0 in. $2\frac{3}{4}$ in 12	16·0 sq. ft. 10 ft. 0 in. $4\frac{1}{2}$ in 12	3·7 sq. ft. 6 ft. 8 in. $2\frac{1}{2}$ in 12
	5 sq. ft. . 0 in.	18·0 sq. ft. 19 ft. 0 in.	20·9 sq. ft. single ...		7·5 sq. ft. 18 ft. 0 in.	15·0 sq. ft. 22 ft. 0 in.	9·0 sq. ft. 16 ft. 0 in.
			Connected.				
	. 0 in. . 9 in. . 6 in. 36 00 6·5 26·0 50 85 $4\frac{1}{2} \times 3$	22 ft. 0 in. 9 ft. 9 in. 13 ft. 6 in. 36 2,900 7·25 29·0 11,200 95 $9 \times 4\frac{1}{2} \times 3$	22 ft. 0 in. 8 ft. 9 in. 13 ft. 6 in. 36 2,600 6·32 26·0 10,050 85 $9 \times 4\frac{1}{2} \times 3$	22 ft. 0 in. 9 ft. 9 in. 13 ft. 6 in. 36 2,900 7·08 29·0 11,200 95 $9 \times 4\frac{1}{2} \times 3$	18 ft. 6 in. 8 ft. 9 in. 13 ft. 6 in. 36 2,190 6·2 29·2 8,430 72 $9 \times 4\frac{1}{2} \times 3$	18 ft. 6 in. 9 ft. 9 in. 13 ft. 6 in. 36 2,440 6·90 32·5 9,400 80 $9 \times 4\frac{1}{2} \times 3$	18 ft. 6 in. 8 ft. 9 in. 13 ft. 6 in. 36 2,190 5·1 15·6 8,430 72 $9 \times 4\frac{1}{2} \times 3$
	30·3 20·3 t. 0 in. 32 ft. 0 in. orter 4 ft.	33·9 ... 33 ft. 0 in. 42-in. B'fly ...	37·1 47 30 ft. 0 in. 32 ft. 0 in. Straight through slide. 19 ft.	41·6	30·3 20·3 63 ft. 0 in. 32 ft. 0 in. Drum 21 ft.	33·9 27·8 34 ft. 0 in. 32 ft. 6 in. 48-in. B'fly ...	30·3 20·3 63 ft. 0 in. 32 ft. 0 in. Drum 21 ft.
	None		None		Babcock & Wilcox 4,570 sq. ft. 45 in. 33,600 690 53·5 4·25		Babcock 4,570 33,6 6
	... ... 150 ft. 6 ft. 0 in.		... ... 150 ft. 6 ft. 0 in.		150 ft. 6 ft. 0 in.		150 f 6 f

CLEVELAND SOUTH PLANT.

	140-Ton Furnace. 39 ft. 6 in. 12 ft. 9 in. 3 ft. 0½ in. 430 sq. ft.		230-Ton Furnace. 48 ft. 0 in. 15 ft. 0 in. 4 ft. 3 in. 655 sq. ft.		80-Ton Furnaces. 33 ft. 0 in. 13 ft. 6 in. 2 ft. 11 in. 380 sq. ft.	
	Gas.	Air.	Gas.	Air.	Gas.	Air.
	3·7 sq. ft.	20·0 sq. ft.	3·6 sq. ft.	14·3 sq. ft.	2·0 sq. ft.	16·5 sq. ft.
	6 ft. 8 in.	6 ft. 6 in.	14 ft. 0 in.	8 ft. 0 in.	15 ft. 9 in.	7 ft. 9 in.
	2½ in 12	5½ in 12	3 in 12	3½ in 12	3 in 12	4½ in 12
	9·0 sq. ft.	18·0 sq. ft.	10·0 sq. ft.	21·0 sq. ft.	6·25 sq. ft.	10·0 sq. ft.
	16 ft. 0 in.	21 ft. 0 in.	16 ft. 0 in.	18 ft. 0 in.	16 ft. 9 in.	18 ft. 0 in.
	18 ft. 6 in.	18 ft. 6 in.	21 ft. 9 in.	21 ft. 9 in.	15 ft. 0 in.	15 ft. 0 in.
	8 ft. 9 in.	9 ft. 9 in.	9 ft. 3 in.	12 ft. 3 in.	8 ft. 0 in.	10 ft. 0 in.
	13 ft. 6 in.	13 ft. 6 in.	16 ft. 6 in.	16 ft. 6 in.	14 ft. 6 in.	14 ft. 6 in.
	36	36	44	44	40	40
	2,190	2,440	3,320	4,400	1,800	2,250
	5·1	5·7	5·1	6·7	4·75	5·9
	15·6	17·4	14·4	19·2	22·5	28·1
	8,430	9,400	12,780	16,950	6,930	8,670
	72	80	89	118	53	67
	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3
			→		← 35 courses 6 × 6-in.	
	30·3	33·9	35·4	45·8	25·6	32·6
	20·3	27·8	20·3	27·8	22	26·5
	63 ft. 0 in.	34 ft. 0 in.	77 ft. 0 in.	43 ft. 0 in.	...	29 ft. 6 in.
	32 ft. 0 in.	32 ft. 6 in.	32 ft. 0 in.	32 ft. 6 in.	34 ft. 6 in.	
	Drum	48-in. B'fly	Drum	48-in. B'fly	Drum	42-in. Forter
	21 ft.	...	22 ft.	...	130 ft.	...
	Babcock & Wilcox		Babcock & Wilcox		*A.B.C.D.*: B. & W., 3,492 sq. ft. *E.*: B. & W., 4,396 sq. ft.	
	4,570 sq. ft.		4,570 sq. ft.		...	
	45 in.		70 in.		40,000	
	33,600		74,000		750	
	690		580		100	
	53·5		148		4	
	4·25		6			
	150 ft.		150 ft.		100 ft.	
	6 ft. 0 in.		6 ft. 0 in.		6 ft. 0 in.	

	Redc
Old 85-Ton	
33 ft.	
14 ft.	
2 ft.	
400 sq	
Gas.	
2·0 sq. ft.	
3 ft. 6 in.	
3 in 12	
3·25 sq. ft.	
7 ft. 6 in.	
5 ft. 0 in.	
3 ft. 0 in.	
ft. 6 in.	
40	
1,800	
4·50	
21·2	
6,930	
53	
× 4½ × 3	
straight th	
25·6	
22	
...	
34 ft.	
Drum	
130 ft.	
H.: B	
6,680	
K.: S	
8,600	
40,0	
7	
1	
100 f	
6 f	

Plate XXXIII.

REDCAR.

Old 85-Ton Furnaces. 33 ft. 6 in. 14 ft. 0 in. 2 ft. 11 in. 400 sq. ft.		New 85-Ton Furnace. 37 ft. 0 in. 14 ft. 0 in. 2 ft. 6 in. 440 sq. ft.	
Gas.	Air.	Gas.	Air.
2·0 sq. ft.	16·5 sq. ft.	3·38 sq. ft.	18·0 sq. ft.
3 ft. 6 in.	9 ft. 0 in.	16 ft. 9 in.	11 ft. 0 in.
3 in 12	4½ in 12	2¼ in 12	6 in 12
3·25 sq. ft.	11·0 sq. ft.	9·0 sq. ft.	17·88 sq. ft.
7 ft. 6 in.	22 ft. 6 in.	18 ft. 6 in.	26 ft. 0 in.
5 ft. 0 in.	15 ft. 0 in.	15 ft. 0 in.	15 ft. 0 in.
8 ft. 0 in.	10 ft. 0 in.	8 ft. 0 in.	10 ft. 0 in.
4 ft. 6 in.	14 ft. 6 in.	14 ft. 6 in.	14 ft. 6 in.
40	40	40	40
1,800	2,250	1,800	2,250
4·50	5·62	4·10	5·11
21·2	26·5	21·2	26·5
6,930	8,670	6,930	8,670
53	67	53	67
× 4½ × 3	9 × 4½ × 3	9 × 4½ × 3	9 × 4½ × 3
straight through; top 5 courses staggered →			
25·6	32·6	25·6	32·6
22	26·5	22	26·5
...	29 ft. 6 in.	...	29 ft. 6 in.
34 ft. 6 in.		34 ft. 6 in.	
Drum	42-in. Forter	Drum	42-in. Forter
130 ft.	...	130 ft.	...
H.: B. & W., 6,680 sq. ft. *K.*: Stirling, 8,600 sq. ft.		*F.G.J.*: B. & W., 5,920 sq. ft.	
...		...	
40,000		40,000	
750		750	
100		100	
4		4	
100 ft.		100 ft.	
6 ft. 0 in.		6 ft. 0 in.	

[*Geary.*

ore. If a mixer has to be heavily fed with ore and frequently drawn from, the metal too often works badly in the steel furnace, a thing that very rarely happens with iron from a scrap-fed mixer.

Furnaces and Equipment.

It will have been observed that progress in fixed furnace construction has tended towards a standardisation of design, so far as the essential features are concerned, with the exception only of the coke-oven-gas furnaces. Any furnace can be adapted for the hot-metal process, provided only that there are means of slagging off whenever necessary. The tilting furnace has a distinct advantage in this, as it has also in the ability to make soluble slag, and in its gain in yield by not losing a little steel in drainings from each heat. The type and amount of equipment in a shop will determine the greatest amount of scrap that can be used with advantage, though a shop that operates normally at greatest efficiency with a relatively high percentage of scrap loses some advantage when the scrap price is high. The charging speed in the works under consideration is seldom too fast; only when a combination of a large amount of heavy scrap and a surplus of charging-crane power occurs should there be need for much warming-up. Extra long tap-to-tap times are more often due to delayed charging than to too-rapid charging.

Fuel.

The question of cold coke-oven gas has been dealt with and an opinion expressed. The rest of the fuel is in the main producer gas enriched with coke-oven gas. It is most satisfactory; in cases where the producer gas is lean it is indispensable to a good performance. In adding coke-oven gas to a better producer gas it is probably advisable to restrict the enrichment to about 185 B.Th.U., except in very long furnaces, as it is sometimes difficult to get the combustion completed with the standard producer-gas port.

Conclusion.

A few years ago Mr. A. Robinson [9] said that he hoped his paper would lead to more open exchange of information than had been possible in the past. This account of the author's experience with hot-metal practice on the North-East Coast is presented with the hope that it, in its turn, may be of some little help to others, and may also hasten the coming of the freedom that was invited.

Acknowledgments.

For the adequate presentation of representative information on the chosen subject of this paper assistance was essential. The melting-shop manager of the Redcar Works, Mr. E. Drewery, and

the manager and assistant manager of the Acklam-Britannia melting shops, Messrs. L. E. Crooks and G. H. Markham, were invited to co-operate in the preparation of the data, and without their willing help the work could not have been completed. The author's best thanks for the help they have given are also due to Mr. E. T. Judge, Mr. C. Moody, Mr. F. Kennedy and their staffs, and to his own staff.

To Mr. F. Shepherd, the General Works Manager of Messrs. Dorman, Long & Co., Ltd., he is indebted for encouragement and advice, and for permission to publish the paper.

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DISCUSSION.

Mr. JAMES HENDERSON (Hon. Treasurer, London) said he would like in the first place to say how greatly he appreciated the references made by the author to the paper presented to the Institute in 1931 by Mr. Robinson on the practice at the Appleby Steelworks. Mr. Robinson had thrown down a challenge, as it were, to other works and other districts to produce data of the full and frank nature which he then gave. It was very gratifying, therefore, to see the data which Mr. Geary now gave in the fullest and frankest manner.

The paper was interesting as giving the practice in five different melting shops on the North-East Coast, which fell into two categories. Two of them were of relatively modern design—he said "relatively," because twenty years had passed since they were designed—and the other three embodied improvements to and adaptations and developments of existing works, following the old-established British practice of carrying on as well as possible with what was available. The data from those two categories of shops were extremely valuable and interesting, and would assist the development which must take place in the district, because it leaped to the mind that here were five shops with a total capacity of about 32,000 tons of ingots a week, and, while geographically one of the shops was separated from the others, there were four almost within a stone's throw of one another, so that the question might be asked "Why have four shops when two would do the work better?" That was a matter which went beyond the scope of the paper, and he was perhaps guilty of an indiscretion in raising it; yet that was a problem which the industry of the country must face if it was to continue in the position which it ought to occupy in the world's production of iron and steel. The question belonged to a larger province of affairs than the purely technical one.

It must have occurred to others in addition to himself that the juxtaposition of the paper under discussion and that of Mr. Harbord on the Thomas-Gilchrist basic process[1] was interesting, and even intriguing. The question of basic Bessemer and open-hearth steel manufacture had been prominent in recent months in the press and elsewhere, and there had been a tendency to suggest that the British steel trade was lacking in initiative because it did not almost jump to the construction of works operating on the lines which had been developed at Corby, and to chide it for not following the example of an all-powerful government of a leading foreign nation. The problem, of course, was not so simple as that, and the answer was almost contained within the district in which the present Meeting was being held, because, as had been pointed out, the basic Bessemer process was first developed commercially in the district;

[1] This Journal, p. 77 P.

that it went out of use in 1919 must be due to some other circumstance than lack of enterprise or energy. The truth probably was that the demand for basic Bessemer steel had been filled by free imports into Britain, and that it became commercially impossible—quite apart from the technical difficulties—to continue its manufacture; but the manufacture of steel on the North-East Coast was continued, and continued effectively, by the basic open-hearth process.

He suggested that there was room for both basic Bessemer and open-hearth steel in Britain, and the operation of tariffs and of trade agreements might make it necessary for the industry to reconsider the question of the manufacture of basic Bessemer steel; no doubt individual works and the British Iron and Steel Federation would give that part of the problem due attention. He submitted, however, that open-hearth steel, and particularly basic open-hearth steel, was the kind of steel on which the country must mainly depend. He would go further and, at the risk of being unorthodox, say that it was his considered opinion that basic open-hearth steel, using the latest process, could be made at a cost not substantially greater than that at which steel could be made by the basic Bessemer process. The process which he had in mind was that which he knew best, the modified Talbot process operating in large tilting furnaces. He had no desire to make any comparison between one district and another or between production in this country and in others; but for any given district in Britain, operating on what had been recently called "lean" ores, that was his considered opinion. He might be wrong, but a close study of the position led him to the conclusion which he had mentioned.

He would like to express once again to the author and his collaborators his congratulations on a very excellent paper. Messrs. Dorman, Long & Co., Ltd., were also to be congratulated on permitting such a mass of data to be put at the disposal of Members of the Institute.

Mr. H. E. WRIGHT (Middlesbrough) congratulated the author on presenting a very practical and useful paper of a type of great value to the proceedings of the Institute. The paper gave in detail six months' average practice with the type of furnaces existing in the North-East Coast district, and it should be very valuable to everyone to compare that with the practice in their own works.

Looking back on the basic process—he himself had been connected with the basic Bessemer process—it was found that the one process which would deal with sulphur in the pig iron was the basic open-hearth process; a considerable amount of sulphur could be removed in the basic open-hearth process, but that was not an economic proposition. After trying everything—high-sulphur, high-silicon irons and everything else—his Company had found that the best method was to produce an iron in the blast-furnace

which was satisfactory for conversion into steel. It was possible to deal with the sulphur, but it meant at least two hours' delay in the furnace.

He would like to refer to the question of fuel. As the paper showed, his Company had been using various kinds of fuel—blast-furnace gas, coke-oven gas and tar—but the economies in fuel, as the results given in the paper showed, were not entirely due to those improvements, because the Redcar Works, which largely worked on producer gas, had a fuel consumption about as low as that of any of the others. He mentioned that point so that sight should not be lost of the main issue.

As he saw it, the problem of the future in regard to the basic open-hearth process was that better refractories would be required. He was aware that the British Iron and Steel Federation had recently put in hand some extensive work in an endeavour to get more done in regard to refractories, but he thought that further progress in the basic open-hearth process would be considerably helped forward by better types of refractories, because the limit for refractories for the roof and sides of the furnace was being approached.

Mr. A. Robinson (Scunthorpe, Lincs.) said that the author had given a most interesting and exhaustive account of the work done and the present achievements in steel melting practice, of which both the author and his Company might be proud; and the opportunity should not be allowed to pass without thanking all concerned for the open way in which the details of their practice had been described. Communications such as the author had presented allowed comparisons to be made which were not odious, and which were the best counter-propaganda against the inferiority complex which, until recent years, seemed to have beset all discussions of the British steel trade. They showed that the steelmakers in Britain could hold their own in equipment and technical achievement with those of any other country, and that, contrary to the often-published opinion, they were capable of taking and had taken their place in the very front rank of progress.

The opportunities afforded to the technical staff of Messrs. Dorman, Long & Co., Ltd., in having such a number of melting shops and such diversity of practice in the same area were almost unrivalled, and allowed close comparisons to be made on such matters as methods of heating and working various types of furnace, which must be of the utmost value to them. They must have settled in their own minds once and for all the comparative advantage and disadvantage of tilting and fixed furnaces; and it was interesting to note that, after trial, nowhere did they use mixed coke-oven and blast-furnace gas without admixture, although they must have large quantities of those gases at their disposal, and that, on the whole, they seemed to prefer producer gas enriched by a proportion

of coke-oven gas. It would be of the greatest interest if the author would give further information on these subjects.

The practice in the tilting furnaces was similar to that employed at the Appleby-Frodingham Works, which were described in 1931 and 1933, with some minor modifications which were considered advantageous at those works, and which partly arose from some difference in the raw materials and plant available. Some recent figures in connection with that plant might be of interest for comparison, the furnaces there having been built for the process and not being converted mixers, as were most of the Dorman Long furnaces. The Appleby shop until recently consisted of three 250-ton and one 300-ton furnaces fired with producer gas alone, and one 500-ton mixer heated with blast-furnace gas, making principally large ingots for plates. A further 300-ton furnace had recently been put into commission, but was not taken into consideration, as it had not yet completed its first campaign. The following were some details:

	250-Ton Furnaces.	300-Ton Furnace.
Hearth at foreplate level	45 ft. × 13 ft.	45 ft. × 15 ft.
Area	560 sq. ft.	650 sq. ft.
Maximum depth	36 in.	36 in.
Gas port	4·75 sq. ft.	4·75 sq. ft.
Pitch	$1\frac{3}{4}$ in. to 1 ft.	$1\frac{3}{4}$ in. to 1 ft.
Air port	13·5 sq. ft.	17·5 sq. ft.
Pitch	9 in. to 1 ft.	9 in. to 1 ft.

The pitch of the ports was quite different from that of the Dorman Long ports. No steel scrap was charged into the mixer. The type of metal was very similar to that at the Acklam works. The fuel consumption was 250,000 cu. ft. of blast-furnace gas per hr. on the mixer and 3·17 cwt. of coal including heating-up but excluding the mixer, taking an average of two years. The output of the 250-ton furnace averaged a little over 2000 tons a week, with a maximum of 2452 tons, and that of the 300-ton furnace a little over 2200 tons a week, with a maximum of 2750 tons.

The particulars of the furnaces at Dorman Long's working with cold coke-oven gas and tar, and the author's tentative opinion as to low upkeep, were particularly interesting; for, although other furnaces in Britain were doing this successfully, no particulars had been published hitherto. With regard to the suggested effect of hydrogen in steel, it would be interesting if the author could confirm that the steel produced in this type of furnace did not suffer from blow-holes more than the normal, and if he would say whether this type of furnace gave a similar yield of ingots to those fired with producer gas.

Mr. F. BAINBRIDGE (Saltburn-by-the-Sea) was of the opinion that all were indebted to the author for his description of plant and practice at five melting shops on the North-East Coast; he

was particularly fortunate in being able to draw on such a mass of data and practice, and, further, in being in the position of having personal contact with all the plants concerned and not having, as was the case with many compilers, to rely on hearsay evidence, which might often consist largely of maximum production figures. The firm of Dorman, Long & Co., Ltd., should also be thanked for permitting such a wealth of information to be made public. The paper was largely a record of fact and did not lend itself greatly to direct criticism, but he thought that it should prove the basis for a general discussion on the principles and practice of steel-making in open-hearth furnaces, and should lead to a more general exchange of information than had been possible in the past.

There were a few points on which he would welcome the author's opinion. He noticed that at Acklam the practice was to nearly empty the furnace into four 75-ton ladles; did the author consider that that practice was superior in speed of output and quality to the so-called continuous process, in which the greater portion of the charge was left in the furnace when tapping a heat? Also with reference to Acklam, he would like to know whether the author found a big loss of dolomite when fettling between taps, in the interval between the first two taps and the second two. At Skinningrove, where four ladles of steel were also taken off the large furnace, they worked another 5 tons of metal during the interval between the second and third taps and made the fettle at the end of the four taps.

With regard to the use of mixed gas, the author mentioned, in paragraph (9) (*a*) of the section dealing with the Acklam works, that slag foaming trouble was experienced and that the luminosity of the flame was not always maintained, and it was suggested that the trouble was due to the moisture of the wet-cleaned blast-furnace gas. Had the author endeavoured to increase the preheat of the mixed gas in the regenerators in order to improve those qualities? The "General Observations" made by the author at the end of the paper would probably be supported by the greater proportion of steelmakers, but it would be interesting to have the author's opinion, in the light of the work which he had carried out, as to whether the active mixer was essential to the hot metal practice.

It would be of interest if the author could give the basis on which the fuel consumption was calculated in converting the various gases in use to coal, and if he could, for the sake of completeness, express the total fuel consumption as heat units per ton, in addition to the coal equivalent, and say whether week-end gas, used for keeping the furnace hot, was included in the fuel consumption given. It would also be of interest to have the author's opinion as to the value, if any, of the tilting furnace in strict comparison with a fixed furnace for the manufacture of ordinary commercial steels.

The author gave a very interesting section on the cold coke-oven-gas-fired furnace. It was probably too early to expect any indication of the economical working of this furnace in comparison with the producer-gas-fired furnace, but if the author could add anything on this point it would be of great value, in view of the fact that the paper contained the first record available of that practice in the Middlesbrough district.

At the end of paragraph (8) of the section dealing with the Cleveland North plant, the author stated very definitely that unless the Hoesch process was worked steel could not be made with a hot metal practice such as that in question without carburising. It would be interesting to hear in what way the practice differed from that at Köln Neuessen, and whether the use of tar was a necessity only in the case of 90% hot metal practice.

Mr. H. S. Wood (West Hartlepool) congratulated the author on an excellent paper. It was not often that the details and results of five large open-hearth plants were so excellently arranged in one paper.

He noticed that in the case of the 250-ton tilting furnaces at both the Acklam and the Britannia works, where only about 22–30% of cold material was being charged direct to the furnace, it was the practice almost to empty the furnaces at every tapping. In the past, when scrap had been so cheap and large percentages had had to be employed in order to keep down the cost of the charge, it had certainly been the better practice almost to empty large tilting furnaces; but at the present time, when there was a scarcity of scrap and it had become necessary to employ larger quantities of molten metal, he thought that the continuous process again demanded very serious consideration. Apart from the increased output, it resulted in less wear on the furnace bottom, a longer life to steel ladle linings, and a more regular supply of hot ingots to the mills.

About eight years ago, while on a visit to Germany, it had been his privilege to visit the Vereinigte Stahlwerke, Meiderich, where he saw a 250-ton Talbot tilting furnace very similar to those described in the paper. This furnace was operating on the Talbot continuous process and tapping 70-ton charges. Its output averaged 366 tons per day, with an average of about 2300 to 2500 tons per week, which was equivalent to about 15 to 16 tons per hr. The cold material charged, all direct, was 25 to 30%. The furnace drew its molten metal from two 800-ton non-active mixers which were being worked as receivers only; they had no gas under them except at week-ends, and those mixers were also supplying the Bessemer shop. The average analysis of the iron entering the mixers was: Silicon, 0·7–0·8%; phosphorus, 1·9%; manganese, 1·6–1·7%. The furnace was fired with a mixture of blast-furnace and coke-oven gas with an average calorific value of 2000 kg.cal. per

cu. m., *i.e.*, 225 B.Th.U. per cu. ft. The gases were mixed prior to their arrival at the plant, but auxiliary coke-oven gas could be admitted at will just before the furnace valves. The gas checkers were worked at a temperature of 1100–1150° C., and the air checkers at 1200–1300° C. By keeping the gas regeneration above 1100° C. no difficulty was experienced in burning this gas, and a clear luminous flame resulted.

He had the pleasure of witnessing a charge worked on this furnace, and he would give the details. The furnace was tapped at 1.10 P.M., when 111 tons remained in the bath. Unfortunately, the furnace was in the process of emptying for the week-end; it was a Saturday afternoon. Two ladles, each of 70 tons, were removed at 1.10 P.M., instead of one ladle. By 3.10 P.M. 25·3 tons of scrap and 46·2 tons of molten metal, along with the necessary oxides and lime, had been charged. At 6.5 P.M., the bath contained 0·14% of carbon, 0·015% of phosphorus and 0·22% of manganese. At 6.12 P.M. the carbon was 0·10%. The furnace was tapped at 6.40 P.M., when a further two ladles of 70 tons were removed. The time for the charge was 5½ hr., equivalent to 13 tons per hr.; but the fact that the bath was low reduced the rate of working, and the average time for a 70-ton charge was 4½ hr.

The furnace for three months had an average heat consumption of 5,153,404 B.Th.U. per ton, but, crediting the steam which was recovered from the waste-heat boiler, the actual consumption was 3,894,100 B.Th.U. per ton. It was making soluble slag containing up to 17% of phosphoric acid, with 80% to 98% soluble. The furnace was very similar in capacity to those described by the author, its hearth being 46 ft. 7 in. long, 14 ft. 5½ in. wide and 2 ft. 11½ in. deep.

He thought that the paper emphasised that for the production of large outputs, which were possible in the manufacture of mild structural steel, constant regularity in working, day in and day out, was essential, and the use of large mixers a necessity in order to provide a supply, regular in analysis, quality and quantity, of molten metal to the plant, and to act as a reservoir so that any breakdown or stoppage at the blast-furnace did not in any way affect the steel plant. He thought that in the case of a plant equipped with such facilities and with present costs the continuous process demanded very serious consideration.

CORRESPONDENCE.

Mr. J. T. WRIGHT (Brierley Hill, Staffs.) wrote that he had read Mr. Geary's paper with considerable interest, as he had given a comprehensive survey of modern basic open-hearth hot metal practice.

The outstanding feature of the practice described in the five melting shops was that progressively increased outputs had been

obtained from individual furnaces, except in those plants where the charging-side equipment and general service units had been overtaxed by the increased output of additional furnaces, with a corresponding increase in total plant output.

Under the heading of "General Observations," the author referred to the mixer practice at Acklam, where a proportion of the available steel scrap was charged into the mixer, and challenged the argument that all the available steel scrap should be charged into the steel furnace. He agreed with the author that the practice of charging all the available scrap into the furnace was wrong, as furnaces with a production rate of from 10 to 14 tons per hr. would lose output if too much time were taken in charging a miscellaneous assortment of steel scrap.

A tilting furnace was primarily designed to deal with a high proportion of hot metal, and the melting rate of steel scrap in this type of furnace was comparatively low.

The addition of steel scrap to the steel furnace would undoubtedly dilute the total metalloids which had to be eliminated from the bath, but the reduction of the slag formation and refining periods would not compensate for the loss of output resulting from the lower melting rate of the charged steel scrap.

This view was confirmed some years ago when he (the writer) had the opportunity of working in a melting shop in which one 250-ton and one 110-ton tilting furnace were supplied with hot metal from a 400-ton mixer. The 250-ton furnace had previously been worked with a charge of 40 tons of steel scrap, the remainder of the charge being hot metal from the 400-ton mixer. Approximately 400 tons of steel scrap were used in this mixer during the week, and the weekly output of hot mixer metal was about 3200 tons. The steel output of the 250-ton furnace was 1700 tons per week.

The practice of charging 40 tons of steel scrap into the furnace per charge was discontinued, and this scrap, amounting to about 400 tons per week, was charged into the mixer, making a total of 800 tons of scrap per week charged into the mixer. This alteration in practice resulted in an immediate increased output of the 250-ton furnace to 1900 tons per week, *i.e.*, approximately 11%.

It therefore appeared advantageous to charge the largest possible quantity of steel scrap into the mixer, and not into the furnace, provided that due regard was paid to the heat of the mixer metal when required by the steel furnace.

The most important aspect of the use of steel scrap now necessarily became a metallurgical one, as its use reduced the total metalloids to be eliminated in the steel furnace, and the consequent shorter slag formation and refining periods increased the output of the steel furnaces charged with this type of hot metal from the mixer.

The author had already shown that the mixers under review

were taxed to their utmost capacity to deal with cold materials, and if the mixers could not, for economic or practical reasons, work a higher proportion of the available steel scrap, then it seemed that still larger mixers, or additional mixers, were ultimately desirable.

It appeared that the present practice in the five melting shops was to leave very little molten steel in the large tilting furnaces, which was a departure from the original Talbot process. This process claimed distinct advantages by leaving 25–35 tons of molten steel in the bath after tapping.

The temptation to tap off the maximum quantity of refined steel was natural, but in the event of the whole of the available steel scrap being charged into the mixer, it seemed desirable that a greater quantity of refined molten steel should be left in the bath. This would reduce the total metalloids of the subsequent charge, which would give a more rapid conversion rate and also reduce the slag volume, giving an increased furnace capacity. These factors would obviously result in some increased output.

When a portion of the available steel scrap was charged into the steel furnace, it would then be advantageous nearly to drain the furnace, as a quantity of cold scrap charged on to 25–50 tons of refined molten steel would set the latter, and delay would be incurred in lifting the partially solidified metal from the bottom.

Mr. G. A. V. Russell (Birmingham) wrote that Mr. Geary deserved to be warmly congratulated on his interesting and informative paper. The operation of five distinct melting shops by one organisation in such close contiguity afforded, perhaps, a unique opportunity for such a paper, since the drawing of comparisons between different types of equipment could be made more readily and under conditions more nearly comparable than was usually the case. It would be generally admitted that Mr. Geary had made excellent use of this opportunity.

One feature of the practices described stood out, and that was the use made in all the plants of the semi-active mixer. At the time when Mr. Wood's paper on open-hearth practice was read at the Prague Meeting in 1930,[1] an observer might have wondered whether the semi-active mixer would not soon become obsolete in the majority of European melting shops. This arose from the conversion in several well-known plants of semi-active or active mixers into large tilting open-hearth furnaces and the employment of enclosed ladle cars of large capacity for the accommodation and transfer of blast-furnace metal *en route* to the steel plant. At the same time several new shops were put down without any mixer capacity. The writer felt, then, that this was a retrograde move, and the return to more normal conditions in the steel industry had

[1] *Journal of the Iron and Steel Institute*, 1930, No. II., p. 111.

shown that the semi-active mixer fulfilled a definite need and was an important factor in reducing conversion costs.

The mixer practice in the various plants described by the author appeared to be characterised by the charging of considerable quantities of cold metal—sculls, steel scrap and moulds. Whilst the diluting effect of the former type of cold charge was doubtless of value in providing metal of lower silicon content to the steel furnaces, one wondered whether it would not be better to charge such material directly into the open-hearth and use the surplus heating capacity of the mixers for additional refining work. Perhaps, however, local conditions dictated that as much solid material as possible be charged into the mixers in order to diminish congestion in charging the steel furnaces themselves.

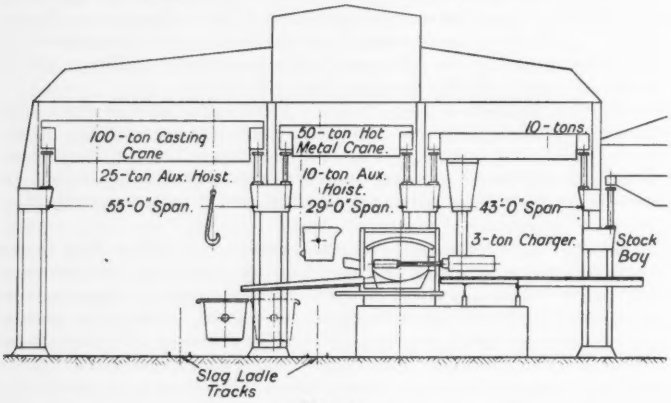

FIG. A.

With regard to the different melting shops described, whilst the first two were relatively old plants, their design had been progressively modified, so that in all essentials they embodied most of the features demanded for modern operating conditions. An exception to this was provided by the pit casting arrangements at the Britannia plant. The three newer shops were fine examples of British practice, they were liberally proportioned and appeared to have adequate crane and charging-machine capacity. The handling of the solid components of the furnace charges was well provided for in all installations, either as a result of good initial design or through judicious improvements which had been made to overcome weaknesses that had become manifest as a result of experience, such as the provision of the extra ramp at the North plant.

The facilities for the reception of blast-furnace metal and the

distribution of mixer metal would appear to be less convenient, and in some cases these were likely to impede the smooth working of the shop. This was not an uncommon defect in hot metal shops, and the writer believed that a radically different general arrangement of crane power was needed to effect a tangible improvement in this important service. In Fig. A he had roughed out the cross-section of an open-hearth plant in which an attempt had been made to provide better facilities for the handling and distribution of blast-furnace and mixer metal. It would be observed that three crane-ways were provided in place of the usual two. The casting bay cranes were of somewhat reduced span, as were also the overhead revolving charging machines. The central crane track served to carry special ladle cranes of small span, for handling the hot metal and servicing the mixer. The line of steel furnaces was so placed as to provide adequate clearance for handling ladles in front. With this arrangement the distribution of liquid charges to the steel furnaces could proceed with much greater freedom than was the case when it must be effected on either the charging or casting sides, as in a shop of normal layout. The layout possessed a further advantage, in that the span of the bridges for the open-hearth chargers was comparatively small, which would increase the handiness of these machines by diminishing their weight and inertia, thus removing the only real objection to the employment of this type of charger. The position for the steel furnaces would necessitate either the provision of a launder of extra length, or, alternatively, the steel ladles would require to be traversed by an auxiliary transfer device into closer proximity to the tapping holes. The writer would appreciate Mr. Geary's reactions to this suggested layout, as it occurred to him when studying the arrangements of the plants discussed in the author's paper, and reading the descriptions of the normal practice in the various shops.

With so much information already given in the paper, the writer felt diffident in asking for more, but in view of the closely comparable conditions in which the different types of furnaces were operating, the temptation to be greedy was great. Thus, it would be of considerable interest if Mr. Geary could give figures for the cost of mechanical maintenance and of power on the large tilting furnaces working at Acklam, Britannia and Cleveland South plants, and also an indication of the capital cost per ton of average output for these furnaces as compared with the efficient large stationary furnaces which were being installed at the Cleveland North and South plants, particularly as compared with the 100-ton coke-oven-gas-fired furnace in the former shop.

In view of the apparently satisfactory performance given by the large tilting furnaces converted from mixers at Acklam and Britannia, it would be interesting to know why, in reconditioning the Cleveland North plant, the second mixer was not utilised in this manner, or, alternatively, in view of the relatively high silicon

content of the mixer metal, why both the mixers in this plant were not kept in commission. The writer would also much like to learn the reasons that led to the abandonment of two of the three small tilting furnaces originally installed at the Redcar Works.

AUTHOR'S REPLY.

The AUTHOR replied that Mr. Henderson, by opening the discussion on the paper, had conferred upon it an honour of which he was deeply appreciative. He was glad that he found in the paper an answer to Mr. Robinson's plea for a greater freedom in the exchange of information.

Mr. Henderson's reaction to the fact that four shops were operating in a comparatively small area was to ask "Why have four shops when two would do the work better?" He said the matter went beyond the scope of the paper, and belonged to a larger province of affairs than the purely technical one. With that the author must agree; but the presence of all the five shops that were discussed was a result of the development of the industry in the district, not only in the last twenty or twenty-five years, but in the last sixty or seventy. Mr. Henderson referred to the old-established British practice of making the best of what was available, and that was precisely what had happened in the case of these shops. They had been erected in each case as near as possible to the sites of blast-furnace plants, the origin of which went back to the founding of the industry in the district.

Mr. Henderson had made a very valuable contribution on the delicate question of basic Bessemer and open-hearth steel, but since he (the author) had not Mr. Henderson's wide knowledge and experience of steelmaking as a whole, he might perhaps be allowed to confine himself to the expression of his satisfaction that the process in which Mr. Henderson placed his faith, the modified Talbot process, was that which he had favoured whenever he had had tilting furnaces in his charge.

Mr. Henderson and other gentlemen who spoke subsequently had offered their congratulations to Messrs. Dorman, Long & Co., Ltd., for permitting the publication of this paper. Just as the Company so freely gave him permission to offer the paper, so now did they allow him to reply to those gentlemen who were good enough to take part in the discussion and correspondence, and also to record their satisfaction that their action in offering the information was so much appreciated.

He was obliged to Mr. H. E. Wright for his kind comment on the paper. Mr. Wright's plea for a better type of refractories would, he thought, receive the support of all who had to operate open-hearth furnaces. His Company had made and was continually

making experiments with refractories, and looked forward to the results of the refractories work of the British Iron and Steel Federation.

Mr. Robinson's kind reception of the paper was very much appreciated. His own papers of 1931 and 1933 already stood out in open-hearth literature, and it was a source of satisfaction to find that, immediately upon the presentation of this paper, Mr. Robinson freely gave to the Members of the Institute the latest information concerning the operation of the tilting furnaces under his control. Such comparative information enhanced whatever value the data in the present paper might have, and he was grateful to him for giving it.

Mr. Robinson asked for further information on the subject of the author's use of surplus gases. In the brief mention made in the paper of the mixed-gas trial it was stated that the outputs from the furnaces were not good, and that previous and subsequent experiences with some form of producer gas invariably showed a better average output. He was prepared to admit that excellent work was being done in many shops using mixed gas; neither was he unmindful of the need for an economical fuel balance within a works; he agreed that there was evidence that lower refractories consumption in open-hearth furnaces might be achieved by the use of mixed gas; but he remained to be convinced that the outputs in certain of such shops were as great as they would be were they using, for example, a perfect producer gas. To each works, therefore, its own conditions and its own problems; his problem for the last few years had been to press every melting unit to its utmost capacity. That was one side of the question, and was, he hoped, a sufficient amplification of the account given on pp. 238 P and 239 P of the paper. The other side concerned the amount of surplus gas available. Mr. Robinson assumed that his firm must have large quantities of these at their disposal; that was true, but relatively they had far less gas than if their blast-furnaces were working a burden composed largely of a lean ironstone. The average coke consumption on the blast-furnaces operated by the Company was about $18\frac{3}{4}$ cwt. per ton of iron, and if the melting furnaces were to use mixed gas, coal would have to be used in places (*e.g.*, boilers) where cleaned blast-furnace gas was a most efficient fuel. Gas producers were already installed at four of the five plants, the other being the Cleveland North plant, which was destined to work mostly by cold coke-oven gas, so, considering all this, they believed that their present distribution was at once the most logical, the most technically efficient, and the most effective.

In answer to Mr. Robinson's questions concerning the steel produced in the cold-coke-oven-gas furnaces, all their evidence showed that the steel was in every way normal, but regarding the comparative yield of ingots given by this type and by producer-gas furnaces, he had no reliable figures nor had he had any reason from general observation to suspect any serious variation.

Mr. Bainbridge, in his opening remarks, said that he thought the paper should prove the basis for a general discussion on the principles and practice of steelmaking in open-hearth furnaces, and at once, in accordance with his belief, launched out on a series of questions that covered almost the whole range of those principles and practice! The author was much indebted to Mr. Bainbridge for his interest in the paper and for his questions. Regarding the working of the continuous process or not in tilting furnaces, he had always found that when he tried the continuous process the rate of output decreased. Such was the case with all the large tilting furnaces in the Dorman Long group, and, as a result of this experience, an appreciable amount of steel was left in the furnace only when it was necessary to work a part charge to bring a furnace into a suitable position for tapping on Saturday morning. There needed be no alteration in the quality of the product, whichever process was worked; if time was gained by establishing a highly oxidising slag in the early stage of working a charge by the continuous process, a correspondingly longer time must be allowed in the finishing period to get the bath in a satisfactory condition. It should not be thought that he had formed a prejudice against the continuous process as such; he had seen it work in a certain shop very successfully indeed, and were it his duty to operate such a shop he did not think that he would have need to alter the practice; the opinion he had expressed was based upon exhaustive trials within his own works.

The Acklam furnaces did not suffer a loss of dolomite by fettling between the second and third taps, since the banks, being at tapping heat and sticky, were in an ideal state for holding the material. It was invariably possible to make a good job of the ends of the banks in this period, and no dolomite fell away during the subsequent tilting.

In answer to the question about the preheat of the mixed gas, he could say that everything that was possible was done to increase it, but, even with all that done, the furnaces did not work satisfactorily.

In connection with the "General Observations" made at the end of the paper, Mr. Bainbridge invited him to make a very wide statement concerning the value of the active mixer in hot metal practice. Hot metal practice was a decidedly elastic term, since it could be used to describe practices that ranged from 100% molten charges with high-silicon iron to charges of 60% scrap with 40% molten iron of low silicon content. Because this great range existed, he must particularise to some extent, and say that it was his opinion that with the irons available at these plants, and with the burdens on which the furnaces worked, the active mixer was essential to the best practice.

Mr. Bainbridge asked for the fuel consumption to be expressed as heat units per ton. The following were the values used in converting the various fuels to coal:

15,000 cu. ft. of blast-furnace gas = 3,300 cu. ft. of coke-oven gas,
" " " = 0·81 cwt. of tar,
" " " = 1·0 cwt. of coal.

The heat units per ton of steel, including all lighting-up, all week-end gas, all bottoming, &c., and all mixers, assuming 80% efficiency for all actual coal gasified, were for the five plants as follows :

Acklam	$5{\cdot}43 \times 10^6$ B.Th.U.
Britannia	6·05 " "
Cleveland North producer-gas furnaces	6·49 " "
Cleveland South	6·22 " "
Redcar	5·58 " "

In answer to Mr. Bainbridge's request for his opinion as to the relative value of tilting and fixed furnaces, he would say that the value of the tilting furnace varied with the degree of standardisation of the required product.

In reply to his questions about the cold-coke-oven-gas furnaces, he was sorry that he could not give Mr. Bainbridge any further information regarding the economy of their operation ; the collecting of reliable data on such a subject was, Mr. Bainbridge would agree, a task that needed much time and patience. The question of the use of tar or not was, in his opinion, bound up with the slag. Of set purpose, in the paper he had confined his comments on this subject to a statement of facts derived from his observation of the working of the process, such observations having been made with sufficient care and under such varied conditions as to leave in his mind no doubt as to the validity of the result. His firm's practice differed from that at Köln Neuessen mainly in the amount of slag-forming material in the burden. His burden was given in the paper ; theirs was mainly the scrap process or hot metal practice with blown metal. His firm's slag volume was about 25% ; theirs, at a rough approximation, could not be more than half that amount. He was not attempting to say that the use of tar was necessitated merely by the presence of an increased slag volume ; he wished merely to record that the practice that he worked made its use essential ; he did not doubt that the tendency to foam was influenced by the composition, viscosity and temperature of the slag, in short, by its reactivity with the metal beneath it.

Mr. Wood, in his very interesting contribution, advanced a very strong case for the use of the continuous process. He (the author) would not attempt to deny the advantages of the continuous process, the chief one being that it would give a more regular supply of hot ingots to the mill. He could only repeat what he had said in answer to Mr. Bainbridge, that he and his colleagues had not been able to make it give the output that they obtained when emptying the furnace. He was obliged to Mr. Wood for giving such a detailed account of the furnace and practice that he saw in Germany ; it was a very interesting record, and just the type of

performance that had encouraged trials in Britain. It would be interesting to know how many large tilting furnaces in Great Britain were working the continuous process, and how many did not work it because it did not give a satisfactory output. Perhaps Mr. Wood might be able to furnish some information on its use in this country; such information would be most useful and valuable.

He had had much pleasure in reading Mr. J. T. Wright's communication, whose first comment called attention to the problem that must have confronted most melting shop operators, namely, that of maintaining the output of individual furnaces when the number of those working was increased. There must be many plants in the country where, during the last ten years or so, improvements in furnace design and in operating technique had been made, while the plants might not have been called upon to work to capacity until comparatively recent years. In such cases the present operators would have been faced with the task of freeing a succession of bottlenecks the probable existence of which could not have been envisaged by the original designers of the plant.

The author was obliged to Mr. Wright for giving the result of his experience when working tilting furnaces from scrap-fed mixers. It was interesting to note that he carried the practice to its logical conclusion, that was to say, he put all his available scrap into the mixer, with a resultant 11% increase in output from the tilting furnace. The practice that Mr. Wright described was worked with one 400-ton mixer serving one 250-ton and one 110-ton tilting furnace. Mr. Wright appreciated that this mixer/ingot-capacity ratio was high in comparison with that existing in his (the author's) shops, and suggested that the author's mixer capacity might with advantage be increased. Mr. Wright's logical conclusion was reached in the light of his own experience, and it was in accordance with the author's own general views. As confirmation, he might say that when the new 500-ton mixer at the Britannia shop superseded the 200-ton one, a marked improvement in practice resulted.

The question of the method of operating tilting furnaces, whether they should be worked on the continuous process or not, seemed to have become one of the major issues arising from the paper. Mr. Wright's remarks were largely confirmatory of his own experience; but perhaps he might point out to him that Mr. Wood's account of the performance of the furnace working the continuous process showed that it was charged with as much as 30% of cold material. He himself had been led to believe that a certain shop that worked the process successfully used on an average about 20–25% of scrap in the furnace.

Mr. Russell, in his valuable communication, raised some most interesting points. As a result of the abolition of the semi-active mixer in many important plants about the year 1930, much attention was naturally focused upon it in those plants where it was still

operating. Its value was about that time very closely investigated by the author's Company, with the result that it was decided not only to retain it, but to develop it as far as possible.

The charging of the mixers with cold materials was governed in all cases by local conditions. Broadly speaking, the general function of the mixers was to supply the requisite quantity of iron, of as good quality and at as high a temperature as possible, to the steel furnaces. To fulfil all these requirements, and to allow the steel furnaces to have the most suitable burden that could be made available for them, it was generally necessary for the mixer cold chargings to be varied in kind. One naturally selected the lighter of the steel scrap to charge into the mixer, and when weight must be gained, then recourse must be had to moulds and pig.

He had much enjoyed studying Mr. Russell's suggested design for an open-hearth plant in which large quantities of hot metal must be handled. It must be admitted that in the shops described in the paper there were times when care had to be taken to ensure that tapping and hot metal charging did not unduly interfere with one another. The idea of confining hot metal handling to a special bay had much to commend it, and it should be readily agreed that it would positively ensure that the hot metal was dealt with without delay, and that the handling of it did not interfere with other work. There were, however, some features in the suggested design of which he was less certain. The narrow span of the furnace bay, whilst it made the overhead charging machine handier, he considered to be a retrograde step. In such narrow shops it was difficult to maintain a clear working space, free from congestion due to feeding materials, piles of melters' tools and the bricklayers' material that must be conveniently placed for repair work; and such shops were at all times, to say the least, very irksome to work in. The hot metal crane, as had been agreed, would look after the metal very well, but what else would it do? Hot metal handling could not be a whole-time job, and it would be a very expensive crane if nothing else were found for it, since normally a crane that usually attended to the hot metal did quite a lot of other work as well. His (the author's) last comment was on the suggested tapping arrangement. He definitely did not like the idea of an auxiliary transfer device on which the steel ladle could stand under a launder of normal length. He would not like to face the position that would result if a stopper should lift while steel was running into a ladle that had been traversed out of the range of any crane that could lift it. The long launder could be used on both fixed and tilting furnaces, provided that the design of the shop ensured that the distance of the tap-hole from the ground was sufficient. A long launder would bring with it certain minor difficulties—time and cost in making and drying, and extra loss of metal as skull—and would of course necessitate fairly extensive stagings to serve it. Of the two suggestions, however, he thought it was the preferable one.

He was not able to give separate figures for the mechanical maintenance and power on the large tilting furnaces, but the following details would, he hoped, provide sufficient information to enable a comparison to be made. The tilting of the furnaces and the moving of the port blocks were in each case done hydraulically, the power deing derived from the ordinary works hydraulic supply. Those special parts of a tilting furnace that called for mechanical maintenance that would not be required on a stationary furnace were mentioned hereunder, together with an indication of the amount of work that was done on them.

The tilting cylinders gave little trouble, the glands, pins and ram pits being inspected each week-end; the rings might need to be freed on an average about every three years. The rollers were inspected and greased weekly. The port blocks had both vertical and horizontal movement, actuated hydraulically; this mechanism gave no trouble, but was greased weekly. The port-face chill castings, torpedo and arch pipes and furnace-end chill castings were changed about every 14 months. The gas and air uptake water-seals were changed as required; usually two out of the six would be changed after each complete campaign. The various walking pipes needed no maintenance.

All his Company's tilting furnaces were either converted mixers or, in the case of two of the Acklam furnaces, tilting furnaces enlarged considerably from their original size. He had been concerned as melting shop manager with certain of these enlargements, each of which had proved to be a profitable investment, but he had not had to do with the erection and subsequent operation of new tilting furnaces; therefore he regretted that he was not in a position to express an opinion as to the worth of the output from new tilting furnaces in comparison with their capital cost.

In reply to the question concerning the second mixer at the Cleveland North plant, it was felt that it was better to keep it in reserve during the starting-up of the plant. If it had been converted to a tilting furnace, the potential output of the shop would have been 8,000 tons, with one 400-ton mixer, in a shop not designed for handling large tonnages of scrap. Since the paper had been written, the reconditioning of the second mixer had been started, and it was anticipated that by the end of the year both mixers would be working.

The small tilting furnaces at the Redcar Works were abandoned because they had never given, under any conditions, outputs equal to those from stationary furnaces of similar capacity. The flame direction, velocity, and temperature had never been as good as they were in the stationary furnaces—in short, the furnaces were "lazy."

REPORTS UPON BLAST-FURNACE FIELD TESTS.

I.—AN INVESTIGATION OF A BLAST-FURNACE SMELTING PRINCIPALLY LINCOLNSHIRE ORES AT THE FRODINGHAM WORKS OF THE APPLEBY-FRODINGHAM STEEL CO., LTD.

By the BLAST-FURNACE REACTIONS RESEARCH SUB-COMMITEE of the Iron and Steel Industrial Research Council.

This Report was published as Special Report No. 18; it was presented at the Autumn Meeting of the Iron and Steel Institute held in Middlesbrough on September 15, 1937. The discussion, correspondence and Sub-Committee's reply follow the summary below.

Summary.

This report, by the Blast-Furnace Reactions Research Sub-Committee of the Iron and Steel Industrial Research Council, presents a short historical summary of previous investigations of the reactions occurring within the blast-furnace, and describes an investigation during which improved methods were devised and successfully established for the determination of temperatures at short intervals across selected horizontal planes in a blast-furnace, as well as for the taking of "gas" and "solid" samples almost simultaneously with each temperature measurement. In order to arrive at a true general perception of the conditions prevailing throughout the stack as a whole, it was necessary to deduce proper statistical averages for the numerous temperature measurements and gas compositions at each sampling point. In view, however, of the considerable variations in such measurements found at each sampling point, and of the importance of eliminating possible errors in the statistical methods employed for determining such averages, the whole of the data were submitted for independent examination to a statistical expert, who reported that, although an enormous number of measurements would have had to be made at each sampling point in order to arrive at an accurate "average" in each case, yet an adequate number had been made for arriving at a valid general view of the actual furnace conditions.

Such "average" results, while generally valid for the particular furnace and smelting conditions concerned, cannot be claimed to be necessarily applicable to other furnaces operating upon other ores and fuel, under widely different conditions as to rates of driving and distribution of the burden within the stack.

Perhaps the most striking and revealing feature of the results

is the fact that the temperature and physico-chemical conditions were found to be far from uniform across any one of the selected horizontal planes in the furnace, thus proving that, in this particular case at all events, any conception of " uniformity " in the conditions across a given horizontal plane must be ruled out as fallacious. In fact, apart from a slight fall in temperature just at the inwall, doubtless due to the cooling effect of the stack-wall and its coolers, the temperatures observed across any given plane were usually higher at the centre and near the inwall than at intermediate points, and reached a minimum at points usually nearer to the inwall than to the centre. Moreover, in descending the furnace such minimum temperature points appeared to move away from the centre, although never approaching less than about 4 ft. from the inwall at any given plane.

Usually at any given point in any one plane in the upper part of the furnace, *e.g.*, 35 ft. below the stock-line, the instantaneous values of the CO_2 and CO contents in the gas followed the temperature in accordance with what would be predicted from the thermodynamical aspect of equilibrium in the principal reversible chemical reactions within the furnace. Moreover, the sum of the CO_2 and CO contents of the gas above this position was nearly a constant.

The expression log CO/CO_2 followed the temperature fairly closely at planes 26 ft. and 17 ft. below the stock-line, but not so closely at the 35-ft. plane. The relationship existing for all the observations made during the investigation is shown.

Two diagrams show the lines of equal temperature and CO_2 content of the gases, respectively, throughout the furnace; they exhibit similar contours for such iso-lines, and particularly for those below 800° C., which may be regarded as characteristic of the working conditions of the furnace. These diagrams show that the furnace was working in what may be termed a centro-annular fashion, with a hot central core, a hot zone near the inwall, and cooler intermediate annuli—a circumstance doubtless connected with the size-distribution of the burden within the furnace. The position of the coldest region, corresponding with that of the highest CO_2 content in the gases, which was almost vertically beneath the periphery of the bell in the uppermost region of the furnace, tended on the whole to move outwards as the furnace was descended. Such conditions were reflected in the further fact that usually along any horizontal plane the degree of ore reduction was greater near the centre or the inwall than at intermediate points between them.

The first diagram also shows that while a definable temperature zone round about 750° C. undoubtedly existed in the upper regions of the furnace, it was so far from being horizontal that the investigation of the relative rate of ore reduction within it was found to be impracticable.

Since most of the stock samples contained iron as well as FeO,

Fe_3O_4 and Fe_2O_3, it would seem as though some condition not usually present in laboratory experiments—when each successive stage in the ore reduction, $Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow FeO \longrightarrow Fe$, is substantially completed before the next begins, there being only slight overlaps at the transition points—existed in the blast-furnace. Indeed, it would appear that in the furnace, as opposed to laboratory experiments, the ore may be as much as 70% reduced and yet retain nearly 30% of its iron as Fe_2O_3, instead of the oxide then being wholly FeO. This circumstance may be due to the larger size of the ore relative to the gas velocity at its surface, and its slower penetration by the gases in the blast-furnace than in most laboratory experiments.

The results of the investigation as a whole may be said to have stressed the importance of the proper sizing and distribution of the solid burden within the furnace. The material comprising the burden of this particular furnace varied in size from lumps of ore weighing 60 lb. (and sometimes more) down to dust, and were charged into the furnace from a bell 13 ft. in dia. with an angle of 45°. The fines and smaller pieces fell from it almost vertically, while the large pieces rolled down towards the centre and the wall, so that the stock-line assumed a wavy contour. And it is principally to such size-distribution of the burden within the stack that the characteristic graphs for equal temperatures and equal CO_2 contents, respectively, may be ascribed.

A further cause of irregularity in the working of this furnace may perhaps be variations in the compositions of the ores used (apart from a small amount of foreign ore), not only from stratum to stratum in the beds, but also along (and away from) the working faces in the mines. The heterogeneity comprised not only the chemical composition, but also the size and hardness of the component strata; consequently a change in the chemical composition of the rocks composing the ores would most likely be accompanied by an alteration in the proportions of the various sizes present. Thus, although a chemical analysis used in burdening the furnace may be used also to determine fairly accurately the ultimate slag composition, it gives no information concerning the changes which will occur in the conditions within the stack when a changeover or alteration is made, because it does not take into account the effect of the physical properties, size and distribution of the component elements throughout the different sizes.

Another factor connected with size-distribution is the influence which it might be expected to exert upon carbon deposition in the upper region of the furnace. In the case of the particular furnace under investigation, it is clear that the most favourable region for carbon deposition would be directly beneath the rim of the bell where the temperature was lowest, the gas velocity slowest, and the ore size smallest. As carbon impregnation and deposition proceeded " voids " would close up, with a further slowing of the

gas stream and increase in the time of contact between the gas and ore in the region concerned, the initial irregularity becoming accentuated thereby.

DISCUSSION.

Professor W. A. Bone, F.R.S. (Chairman of the Blast-Furnace Reactions Research Sub-Committee of the Iron and Steel Industrial Research Council), in presenting the Report, said it was the outcome of an enterprise of considerable magnitude and difficulty, which had been financed and organised by the British Iron and Steel Federation. It could be claimed that no such thorough investigation of blast-furnace plant had previously been made, although a good many investigations of the kind had been carried out in both this and other countries. A great amount of consideration had been required with regard both to the apparatus and methods used and to organising and carrying out the work on the plant, especially as it had to be carried out without any interference with the normal working of the furnace, a condition which necessarily imposed limitations on what could actually be carried out.

They had done their best at Frodingham, under the conditions obtaining there, and the Sub-Committee wished to congratulate Dr. Stacey Ward, their officer in charge of the investigation, on the effective way in which he had organised and carried out all the work, which had been of a very arduous and difficult nature. The Panel of the Sub-Committee had paid several visits to the works during the investigation, in order to satisfy themselves in regard to the apparatus designed for the work. In that connection they were indebted in particular to Dr. D. M. Newitt, the well-known chemical engineer, for the trouble which he had taken, after joining the Panel, in designing the apparatus to be used, especially for the temperature determinations and for the extraction of the gas samples; for the success of that part of the work had been due very largely to his help.

The Sub-Committee had also to thank the staff of the Appleby-Frodingham Steel Co., Ltd., for their very effective co-operation. For, in addition to the personal co-operation of Mr. Crooke, to whom the Sub-Committee were greatly indebted, and that of his technical staff, a small force of his workpeople had volunteered to assist in the daily carrying out of the experiments, and Dr. Stacey Ward had been able to drill and make them very efficient in regard thereto, and all concerned had co-operated in a most commendable spirit. They had caught the true research spirit during the course of the experiments, and had carried out the work with the utmost enthusiasm and efficiency. Such assistance from the workpeople themselves had been a most satisfactory feature of the investigation, and he would like to convey to them the grateful appreciation of the Sub-Committee.

There were two points which should be borne in mind. First of all, the results obtained, and such conclusions as could legitimately be drawn from them, must be considered as pertaining only to the particular circumstances and conditions of the Lincolnshire smelting process. The particular ore or mixture of ores, as well as the particular coke and working conditions involved, would differ from those obtaining in other smelting areas, and the results and the conclusions drawn from those results could not necessarily be extended to other conditions. Secondly, in the case of the particular furnace investigated, the character of the burden was liable to change from day to day, and sometimes almost from hour to hour, owing to the fact that the composition and the grading of the ore were liable to considerable change, sometimes within a short period of time. The furnace burden as a whole, in regard both to the fuel and to the ore, was liable to a greater amount of change than would be experienced, for instance, in smelting Cleveland stone with Durham coal, and that had made the investigation more than ordinarily difficult. It had meant taking a great many more observations than would otherwise have been necessary in order to arrive at correct average results. Undoubtedly the peculiar temperature distribution found throughout the furnace had been due largely to the heterogeneity of the burden and to frequent variations in the local conditions.

Mr. W. J. Brooke (Member of Council, Scunthorpe, Lincs.) said it would be agreed that the Report constituted a monumental piece of work. The data given were so voluminous that a considerable time must elapse before their full effect could be assessed and any reasoned opinions formed. It was, however, very interesting to those who had spent the greater part of their lives in trying to make reasonably cheap pig iron of a suitable character in the conditions which existed at Frodingham to have it put on scientific record that the conditions were so difficult. From the practical standpoint, what came at once to one's mind was that the peculiar variations shown in Figs. 36 and 37 indicated what he thought many blast-furnace managers in Lincolnshire had for many years felt sure was the case, namely, that the distribution of the material in the furnace was causing very great differences across the horizontal section of the furnace. That feeling had very often been emphasised when emptying the furnace out after working.

He greatly appreciated the fact that the Report stressed the importance of the pre-preparation of the ores before they went into the furnace. If it did nothing else, it would be of enormous advantage to those in Lincolnshire who had had the courage to attempt the pre-preparation of the ores to a greater or less extent; and, whilst the work which was being done at the present time might not be absolutely final, it at any rate showed that steps were being taken in the right direction.

Everyone concerned in the work described was to be congratulated on the very ingenious way in which the difficulties which had to be faced, and which must have been enormous, had been overcome. It was interesting to those who had been troubled from time to time by the varying conditions in the working of blast-furnaces and by the day-to-day difficulties which they experienced, to have it on record that these were due to the circumstances of the district. It was very desirable, and he thought very necessary, that further information should be made available with reference to other districts, and he sincerely hoped that the work which had been commenced at Frodingham would be carried out in other parts of Britain, so as to obtain the fullest information possible. To a large extent, the Report confirmed a great many of the opinions formed as a result of the investigations made by Sir Lowthian Bell fifty-five years ago; they seemed to show that the work which was done then was definitely on the right lines, and was being confirmed by more up-to-date practice.

Mr. R. A. HACKING (Rotherham) said he had had the opportunity of seeing one or two of the test runs with the sampling tube, and the smoothness with which the arrangements functioned, and the speed and lack of fuss attaching to the whole operation, were remarkable; congratulations were due to all concerned.

He thought that the principal point to be derived from Figs. 36 and 37, the isothermal and iso-CO_2 diagrams, was the enormous gradients which existed along horizontal planes in the furnace. These might seem rather surprising to the hitherto uninformed and rather terrifying to those who had to work blast-furnaces, but he thought that the conformity of the two diagrams to one another was sufficient proof of their authenticity. Further, the form of the two diagrams was, in a very general way, similar to that for the Holt and Illinois furnaces investigated by Kinney and his collaborators. When one reflected on the dissimilarity of the three units—Frodingham, Holt and Illinois—in regard to dimensions, lines, character of raw materials, burden/fuel ratio, and so on, this general conformity to what was undoubtedly an unsatisfactory state of affairs from the standpoint of furnace efficiency alone, might seem rather surprising. For instance, the Frodingham furnace was using lumps up to 60 lb. or more in weight; the Illinois furnace was using Mesabi ores containing something like 60% fines, 30% rubble, and 10% lumps up to 3 or 4 in. in size; yet the two units, completely different in dimensions and in regard to raw materials and other factors, gave very similar diagrams. Obviously it was necessary to look for a common factor, and to his mind the obvious circumstance common to all three cases was the method of introducing the raw materials into the shaft, and the general proportioning of the bell to the diameter of the throat. All three cases adhered fairly rigidly to the conventional "2-ft. wide annular ring." The Frodingham furnace had

a 13-ft. bell and a 17-ft. 1¼-in. throat; the Holt furnace had a 10 ft. 3-in. bell and a 13 ft. 3-in. throat, while the Illinois furnace had a 13-ft. bell and a 17-ft. throat.

That it was possible substantially to change the isothermal and iso-CO_2 diagrams by altering that proportioning was, he thought, demonstrated very graphically by the corresponding diagrams relative to the United States Bureau of Mines experimental furnace. It was admitted that that was a very small unit, with a 36-in. throat and a 20-in. hearth. At the same time, the means available for introducing the materials into that furnace were in effect very different from those obtaining on full-scale blast-furnaces, and as a result a completely different sort of diagram was obtained. There was a shaft of cool gas up the centre of the furnace, with hotter gases richer in CO streaming up the walls; there was no suggestion of a hot centre, an annular ring of hot gases and a sort of cool ring in between.

Whilst the crushing and grading of the ingoing solid materials—ore, fuel and flux—could effect substantial improvements along the lines indicated, it was his firm contention that so long as the conventional bell and hopper were employed, the general form of the diagrams in question would remain substantially the same, barring the road to technical progress. It was perhaps as well for the industry that technical attainment did not invariably spell economic progress, and as long as the blast-furnace fulfilled—as in the majority of cases—the subsidiary (and erstwhile primary) function of a gas producer, the urge to utilise to the full the reducing powers of the gases passing up the shaft was far from sufficient to warrant radical engineering changes of the nature indicated. However, he would like to wind up the consideration of this point with the thought that, whilst the blast-furnace had reigned supreme in its own particular field for several centuries, it must not be regarded as the be-all and end-all of the reduction of iron ores. When it came to putting the solid materials into the shaft of a blast-furnace, one was using an appliance which, in terms of gas producer practice, was something like thirty years behind the times.

There were a few small details which he would like to mention. In Table XV. there was one rather freak sample, No. 687, which at a level of something like 22 or 23 ft. above the tuyeres possessed a temperature of 1225° C., a CO_2 content of 3·15%, and a $CO + CO_2$ content (35·7%) very similar to that of tuyere gas. The question might arise as to what a sample of that description was doing at that height above the tuyeres. It had three things wrong with it: It was too high in temperature, it was too high in CO_2, and it was too low in $CO + CO_2$. It was obvious that there must be some abnormal condition to account for it. In his opinion, it confirmed the idea of many practical blast-furnace operators, that when channelling did occur it was primarily due to premature fusion, improper distribution, irregular and selective descent, &c., of the iron-bearing

materials, which in some way or other became isolated from the coke which should go with them. To his mind, the only reason that would account for those three abnormalities occurring in company—high temperature, high CO_2 content and low $CO + CO_2$ content—was that there must be a stream of hot, high-velocity gases through a " channel " walled with partly-reduced iron oxides, and deficient in coke and the carbon of impregnation and deposition which Professor Bone had dealt with in previous papers.

At the end of paragraph (7) of the Summary and Discussion, the statement was made that " such conditions were reflected in the further fact that usually along any horizontal plane the degree of ore reduction was greater near the centre or the inwall than at intermediate points between them." He thought that that statement required qualification. He admitted that it was undoubtedly quite true in regard to the samples withdrawn from the furnace, and, further, that the solid sampling tube and the technique employed in getting it in and out of the furnace were by far the best which had been used by anyone up to date. At the same time, he could not agree that the sampling tube took from the furnace a true sample of the solid materials; to his mind the fact that the degree of ore reduction would appear to be greater in the vertical or semi-vertical zones, where there was a concentration of lump ore, proved that the sampling tube selected the fine material which was detached from the ore pieces and virtually ignored the inside of the lumps. If it were possible to take, say, a foot cube of material from those three positions—annular ring, intermediate, and central zones—he would expect the authors' findings in this regard to be completely reversed.

It should be remembered that in any counter-current system, such as the one under review, the chemical and thermal characteristics of a reactant at a given point were not only a cause, but also an effect. The point should be stressed that the conformity of the iso-CO_2 and isothermal diagrams arose primarily from the fact that the latter indicated temperatures relative to the gas phase *only*. The lag of the descending solids behind chemical and thermal equilibrium was very much greater in the zones where concentrations of lump ore occurred. Consequently, the streams of hot, CO-rich gas were indicative of inability to make contact with the relatively unaffected interior zones of lumps coated with a thin layer of material in an advanced state of reduction. It was his firm contention that they could not arise from a more advanced state of reduction in the zone as a whole.

Mr. E. C. Evans (London) remarked that in his last paper submitted to the Institute Professor Bone had pointed out a fact which up to that time had been quite unknown, but which appeared to have considerable importance, namely, that at a temperature of the order of 750° C. the velocity of reaction between the ore and reducing gas was considerably decreased. That fact appeared to

be of such significance as to prove a stimulus to the exploration of operating blast-furnaces, for the purpose of determining whether such a zone of reduced reaction velocity existed. The present work was largely the result of that stimulus. A study of the results failed to indicate that such a zone did exist, largely owing to the conflicting conditions in the furnace; but he thought that it would be agreed that the work described, although it had not thrown any light on that particular subject, was of great significance in practical blast-furnace operation. As a piece of works research—he used the word "research" advisedly, and he thought that Professor Bone, who was a great classical experimentalist, would agree with—it had certain features in common with all works research. Difficulties of technique, of measurement, and of manipulation had to be overcome; and, when all the mass of data had been obtained, there remained the problem of interpretation, which involved statistical methods. It was a very remarkable example of a piece of works research of both scientific and practical interest.

Two points which he would like to make had already been referred to by Mr. Hacking, namely, the correlation between the isothermal lines and the lines of equal CO_2 content in the furnace and the importance of bell and throat design in furnace operation. He would like to see the work furthered by an examination of the hearth conditions. All blast-furnace managers emphasised the importance of the hearth as a determining factor in blast-furnace operation. He would like to ask whether it was possible to continue the work by an exploration of the hearth as well as of the zones of rather lower temperature. He knew something of the difficulties involved in high-temperature experimental technique even in the laboratory, and in the blast-furnace they would be still greater; but possibly something might be done even in the present series of experiments. It might be possible, for example, in connection with the work in question, to determine the volume of air supplied by each individual tuyere, and to determine whether the air blown was uniformly distributed throughout the hearth of the furnace. That would not be difficult. He would suggest to Professor Bone and his Sub-Committee that consideration be given to the extension of the work to the examination of the hearth zone, which was of such tremendous importance in the ultimate efficiency of operation.

Mr. T. Hoskison (Brierley Hill, Staffs.), speaking as a member of the Sub-Committee, said he wished to support the thanks which had been expressed to Dr. Stacey Ward and the officials of the Appleby-Frodingham Steel Co., Ltd., for the very thorough manner in which they had carried out a most difficult piece of research. Thanks were also due to the Appleby-Frodingham Steel Co. for the permission given to publish the very complete data of their furnace working at Frodingham, data which in his opinion would repay the consideration of all those engaged in blast-furnace operation.

The results themselves were merely a confirmation of a theory which had long been held amongst blast-furnacemen, namely, that successful blast-furnace operation was the result of an average of a number of constantly varying reactions throughout the furnace. Mr. Hacking had referred to the influence of the bell diameter upon the operation of the blast-furnace, and personally he was of opinion that Mr. Hacking's remarks were the only valid conclusion which could be drawn from the Report. So long as charging mechanism of the bell and hopper type was used, it would be necessary to put up with the heterogeneity which had been disclosed by the results obtained in the research which had been carried out. He was the more confirmed in that opinion by his experience in operating what many might consider an anachronism in these days, namely, open-topped blast-furnaces. In such cases it was, of course, possible to watch the burden descending in the furnace and have it constantly under observation. His experience was that, provided that such furnaces were kept completely full and that therefore there was no considerable drop of the material from the furnace barrow to the top of the burden, sizing of the burden did not take place, and under those conditions such furnaces worked perfectly uniformly and with very little trouble. He had, however, deliberately allowed the top of the burden in such a furnace to descend 8–10 ft. below the furnace top and had observed the material for many hours. He found that distinct sizing took place under such conditions, and was followed in due course by a considerable irregularity in the working of the furnace.

He considered, therefore, that until some method of charging other than the bell and cone was obtained, all furnaces would be subject to the heterogeneity displayed in the present research, and any preparation of the ores, however complete it might be, could not be 100% perfect and would still result in size separation of the burden when it dropped from the bell. That was proved, as Mr. Hacking mentioned, by the experience of the use of Mesabi ore in America; size separation had still taken place there. Although that size separation might not be of the ore itself, there were other materials in the burden besides ore.

He was not altogether in agreement with other speakers with regard to Figs. 36 and 37, which had been referred to as the iso-thermal and iso-CO_2 diagrams; he was inclined to think that those who had referred to them were being led away by the beautiful symmetry of the figures into imagining that they showed what happened in the blast-furnace. That was not the case. The data on which they were based were a series of spot determinations taken over a very considerable period; at any moment following the one at which they were taken an entirely different result might have been obtained. The diagrams might, as an average, be valid for one half of the furnace under consideration, but he was quite sure that they were not valid for the second half of the furnace; they

could not be a mirror image of that half in which the data were obtained.

His reason for saying that would be brought out if the plan of the furnace given in Fig. 2 were examined. From this it would be seen that the experiments were made upon two adjacent vertical lines on the furnace shaft. On the opposite side from that position there were two slag notches, a tap hole, and, at the top of the shaft, two gas outlets. He had found that that half of the furnace in which the two slag notches, tap hole and gas outlets were situated always worked more rapidly than the other half. Proof of this was evident to blast-furnace managers when they took such a furnace out of commission and found the lining much more worn away on that half on which gas outlets, slag notches, &c., were situated. Therefore he submitted that Figs. 36 and 37 could not be regarded as being absolutely correct; they were to a certain extent imaginary. They were not imaginary, of course, in so far as they showed the absence of a horizontal temperature phase in the furnace at any one point; the fact that such a horizontal line did not exist had always been within the knowledge of blast-furnacemen. The very nature of the charging operation was a proof of that. If they were regarded as an instantaneous representation of conditions which were in actual fact moving rapidly up and down he would be prepared to agree with them.

With regard to the solid samples, which it was to be regretted were not greater in number, he thought that one interesting conclusion could be drawn, namely, that, disregarding the annulus, the same degree of reduction could be obtained over a depth of 15–20 ft. in the furnace, showing, to his mind, that the furnace height could be usefully reduced. He thought that if some charging method could be made available which would do away with all size separation in the furnace, it would be found that furnaces for outputs similar to those being obtained to-day could probably be reduced at least one half in size, with very considerable economy in coke and with cheaper working of the furnace generally and far less trouble.

He thought that the Report could be regarded as epoch-making. The research was the most thorough and complete which had been made up to date, and ought to be followed by a complete survey of the whole blast-furnace practice in Britain. The British Iron and Steel Federation, in his view, would be failing the industry if it did not carry the work forward to investigations of the reactions which took place in every iron-producing district in this country. He would also like to support the plea made by Mr. Evans that the investigation should be extended to at any rate an estimate of the amount of blast entering the furnace throughout the periphery of the tuyere zone. In his opinion, this was a far more important factor in distribution than was generally realised. He did not think that it was as important as the question of the distribution of the raw material at the top of the furnace, which he considered to be the

absolute limiting condition of present blast-furnace practice, but he was of opinion that the correlation of blast volumes entering at each tuyere with the data to be obtained in subsequent investigations would be very important.

Sir WILLIAM LARKE, K.B.E. (Vice-President, London), congratulated Professor Bone not only on the results of the work as presented now but on his recovery from a very serious operation. It was only Professor Bone's indomitable physical and moral courage which had enabled him to present the Report in person. Personally, he had been privileged to be in constant contact with Professor Bone in connection with the work described in the Report, and he could give the assurance that in every conscious moment since his illness Professor Bone had endeavoured, from the nursing home and the sick-room, to be in active touch with the progress of the work. The Members would desire to offer him their cordial congratulations on his recovery and to express the hope that he might long be spared to exercise his great scientific knowledge and experimental gifts in the interests of the industry.

There was one comment which he would like to make on the Report. He did not believe that there was anyone in the industry to-day who would cavil at the expenditure of money on research in the quest of knowledge for its own sake, but, if there were, the work under discussion was an outstanding example of the value of such a quest. Professor Bone undertook investigations into the reactions in the blast-furnace some ten years ago in the laboratory, to bring up to date the wonderful work of Sir Lowthian Bell; and, as a result of his laboratory work, which might at that date be said to be the quest of knowledge for its own sake, he produced papers that resulted in the present investigations which had had such remarkable results.

Coming down to the mundane level of costs, it was unnecessary to point out that the Report opened up a wide horizon of great potential increase in the efficiency of blast-furnace operation by increase in fuel economy. If, therefore, anyone ever again raised the question of the value of research in the quest of knowledge for its own sake, it would be sufficient to point to the present results.

In conclusion, he appealed to all those responsible for the management and operation of blast-furnaces to give the Report that detailed consideration which under the stress of conditions of such a Meeting as the present one was impossible, and to communicate their results as fully as possible to the British Iron and Steel Federation. Mr. Hoskison suggested that the Federation should continue the survey throughout the country. Personally he considered such a survey essential, and he had no doubt that the industry would make it possible for the Federation to complete that survey, in connection with which he would like to express the appreciation of the Federation to the firms who had co-operated so generously in placing

furnaces, staffs and every facility at the disposal of the investigators. He would like to pay a particular tribute to Mr. Clements, of Park Gate, Mr. Crooke, of Frodingham-Appleby, and to the Skinningrove Company, where further investigations were now in progress.

CORRESPONDENCE.

Mr. J. H. HARRISON (Middlesbrough) wrote that best thanks were due to Professor Bone and his co-workers for this very complete and fully detailed Report. Its value was more far-reaching than could at present be appreciated, and it would be looked to in years to come for data relating to the subject with which it dealt.

He thought that one of the most important points in the Report was that relating to the lines of equal temperature and of equal CO_2 content within the stack, taken on various horizontal planes through the stack, and shown in Figs. 36 and 37. These had been very carefully plotted, and gave very valuable and definite information as to the working conditions inside the lower portion of the stack with regard to the material travelling down towards the melting zone.

It had for long been known that the charging of materials by the bell and hopper arrangement, as shown in Fig. 38, had the effect of throwing the larger materials to the side walls and to the centre of the furnace, that the smaller and fine materials remained at about the point where they dropped vertically from the lip of the bell, and that these smalls remained in nearly the same position vertically until they reached the melting zone, with the result that the gases always found easier passages through the larger materials at the centre and near the side walls. But he had not before realised that there could be such a wide difference in the furnace due to these conditions as was definitely indicated by the very varying temperatures shown on any of the horizontal planes in Fig. 36.

He thought he was right in saying that, ever since blast-furnace tops began to be closed, this had been done by bell and hopper (or cup and cone, as it used to be called), but after what had been shown in this Report, it seemed, to him, obvious that some other means of charging furnaces would have to be devised, which would avoid this very great irregularity across the horizontal plane of the stack of the furnace, both in regard to temperature and CO_2 content, which, he thought it would be agreed, must be a considerable disadvantage, as it prevented uniform working conditions from being obtained in the furnace.

Perhaps Professor Bone would say what, in his opinion, would be the benefits if the temperature and CO_2 content could be maintained fairly uniform across the horizontal planes, instead of being so widely irregular as shown by the diagrams.

He thought it might be possible to design a rotating chute connected to a central hopper fixed at the top of the furnace, in place of the usual hopper, so arranged that after this hopper had been filled, it and its attached chute could be made to rotate and deliver the material round the whole area of the inside of the throat of the furnace. The delivery spout from the chute would be straight, and radial from the centre of the furnace. In this way the large and small materials would fall together on to the top of the burden in the furnace, and stay where they fell. This would prevent the large materials from separating out and running away down to the sides and centre of the furnace, leaving the small where it fell, as happened when the bell and hopper were used.

This was only a rough suggestion for preventing the large materials from separating from the smalls, which really should be the essential aim, and there might be other means of achieving this more efficiently.

In any case, if the avoidance of these irregular conditions inside the blast-furnace would bring about more efficient furnace working—and he thought it would—then it was only one more problem for blast-furnace engineers to tackle, and after what they had overcome in the way of mechanical charging in recent years, he felt sure they would succeed equally well in producing mechanical means for the even distribution of materials charged into the furnace.

Mr. C. S. GILL (Sheffield) wrote that, whilst associating himself with the remarks of those who took part in the discussion, he would like to point out that when the results were really appreciated it would appear that nothing had been learned that was not known previously so far as the broad principles of the operation of the blast-furnace were concerned. What the Report had done was to confirm what was already suspected.

Professor Bone, in presenting the Report, commented upon Figs. 36 and 37, mentioning that it was to be expected that those lines would have been approximately straight across the furnace, and it might be assumed that, were it possible to obtain absolute uniformity, so that the material across any plane was equally sized and distributed and the volume of gas rising through the furnace was perfectly uniformly distributed, then the straight lines mentioned by Professor Bone would be attained. Such ideals being impossible, it appeared evident that the diagrams referred to were an indication of a ratio of two physical conditions, namely, the proportion of lumps and smalls in the charge, and the ratio of the area of the bell to the throat area.

In view of the statement made on p. 94, paragraph (10), relative to the size of the lumps of ore, it was quite possible that the diagrams showed a condition of affairs in the stack worse than was generally obtained in a furnace where no unduly large lumps of material were allowed to be charged.

He would certainly advocate that further tests should be made, and it would probably be found that from the two detailed results thus obtained it would be possible, knowing the physical condition of the charge and the ratio of the bell diameter to the throat diameter, to plot the lines for any furnace without spending time in taking the tests throughout the whole country.

The variations in chemical composition of the ores would not, in his opinion, greatly change the lines in the diagrams, though they would probably have an influence upon the *range* of temperatures and CO_2 contents in the furnace.

He thought that everyone who studied the Report was bound to congratulate all concerned in its production on the excellence of the work accomplished.

Dr. M. L. BECKER (Teddington) wrote that one matter which had not been commented on in the Report was the uncertainty of the results of solid sampling at the different levels in the furnace. It would be noted, for instance, that the degree of reduction appeared to be little changed as the burden descended from the level of row *G* to that of row *D*. This was fairly obvious from the diagrams shown in Fig. 34A, but could be more clearly demonstrated by considering the average degree of reduction at corresponding distances from the inwall. These averages were given below and had been calculated for planes *G* and *D* from four sets of measurements recorded for each plane in Table XIX. :

Average Percentage Reduction.

Ft. from Inwall	2	4	6	8	10	12
Row *G*.	85	76	70	73	72	...
Row *D*.	66	65	68	78	82	73

Although this treatment of the data obtained might be open to certain objections on account of divergencies, it clearly indicated that, whilst some reduction occurred near the centre of the furnace, the bulk of the ore appeared to be slightly oxidised on passing down the stack from the level of row *G* to that of row *D*, a distance of about 9 ft. It might be suggested that the above figures deduced from the solid samples were some confirmation of the low reactivity which had been found at about 750° C. in the laboratory experiments,[1] although the temperatures recorded within the zone were decidedly above 750° C. The evidence, however, did not seem to be reliable, for, although the treatment of the samples and their analysis were beyond question, it was doubtful whether the samples withdrawn by the tube were truly representative of the stock at the particular level investigated. Probably small pieces of ore, and the outer portions of large masses, predominated in the samples, so that figures

[1] Bone, Saunders and Rushbrooke, *Journal of the Iron and Steel Institute*, 1934, No. I., p. 47.

obtained for the degree of reduction would tend to be too high, particularly at the higher levels in the stack. Had it been possible to use a larger tube, the sampling error might have been reduced, but it certainly would not have been eliminated when, as stated on p. 9, the size of the ore charged varied " from lumps often weighing 2 cwt. down to dust." Whatever the effect of such variation on the smooth and efficient running of the furnace, it seemed doubtful whether an accurate survey of the progress of reduction could be obtained unless the ore charged were reduced to more regular size.

It would be interesting to know if Dr. Ward had any information bearing on the reliability of the solid samples. He (Dr. Becker) had raised the matter as a warning to those who might apply the results of solid sampling, and not as an adverse criticism of work which all would recognise to be of a very high standard.

Mr. C. A. Julius Behrendt (Scunthorpe, Lincolnshire) wrote that at the outset he would like to state that he had no serious criticism to offer on this Report, as the methods adopted, the tabulation of the data obtained and the conclusions drawn therefrom seemed to him to be correct. Indeed, as one who was rather closely associated with the operations which formed the basis of the Report, it would probably ill become him to do so.

One or two points, however, some of which had been raised in discussion, seemed to him to be worthy of further comment and emphasis. The authors had been criticised for having duplicated the isothermal and equal-CO_2 lines in Figs. 36 and 37 to complete the diagram for the whole cross-section of the furnace. In the absence of data to prove this to be faulty, he thought it was quite a logical thing to do, and from his knowledge of the furnace he had no reason to believe that another series of experiments, conducted at points diametrically opposite to those used, would give results on the average very widely divergent from those obtained. In fact, he felt quite convinced that the variations and vagaries obtained on the one side would be just as pronounced at some other place in the furnace section, but that from them would be built up a diagram very similar to that produced. In any case if the figures for one side were carefully considered he thought the conclusions were quite justified.

In his view a study of the coke characteristics, from the Tables given, should go some way to account for some of the wider divergencies in the results obtained, as it must be borne in mind that any one of these coke qualities might have been charged in a batch of appreciable size, and he imagined that the behaviour of these coke qualities would be as heterogeneous as the tabulated characteristics.

In the matter of distribution of material from the bell, he would like to utter a small criticism on Fig. 38, showing the contour of the stock-line. He thought that the hollow of the stock-line where it

met the inwall was somewhat over-drawn. He did not think that under normal conditions the pile of finer material under the periphery of the bell was far enough away from the wall to form a bank down which rough material could roll towards the wall. He thought that the annular zone of coarser material at the inwall was composed of the stuff that was sufficiently free-flowing to gain enough velocity on leaving the bell to carry it to the wall, but not enough to rebound from it, so that it came to rest against the wall. In other words, it was probably rather small-to-medium sized ore, and much of it was of a somewhat softer nature.

The data obtained did, to his mind, undoubtedly prove that the size segregation of materials across the diameter of the furnace, into annular rings, begot a set of conditions which persisted into the lower regions of the furnace, probably with detrimental effect to the smelting process.

So long as a circular bell and hopper were used for charging, the central circular crater would exist, which, by its increased depth and the increased steepness of its banks, could assume very serious proportions, particularly with materials in bad physical conditions.

The idea of working with concentric bells had attractions, but complication of the top gear of a furnace was much to be avoided, and he confidently anticipated that considerable benefit would accrue in practice from a more rigorous crushing of the ores and the extraction and sintering of the fines. Crushing the coke to regular size had also much attraction to him.

To turn to the results of the solid sampling, he must confess that he had been rather disappointed. Though one could trace very crudely a general tendency for the degree of reduction and carbon impregnation to vary in conformity with the "iso" lines plotted for the gases, the variations were so widely divergent as to make deductions very insecure.

He held the view that many of these major irregularities arose from the fact that the samples were composed of ores of very different reducibilities, rather than from the variation in particle size, to which they were attributed in the explanation given in paragraph (9) on p. 94. He thought that, in all probability, the persistence of large particle size depended on whether the particle were reactive or not. He was pretty sure that the various strata of which the Frodingham ironstone bed was composed possessed very different reactivity characteristics. This, he thought, emphasised the importance of following up investigations into the reducibilities, though to what extent the knowledge so gained could be utilised, he would not at present care to forecast.

The criticism that the method of solid sampling only took the fines and left the lumps, caused him little perturbation, as he believed that, even at the top sampling level, the percentage of lump ore remaining as such was quite small.

The disruption and disintegration of the ores were well advanced

at comparatively high levels. The relative position of this zone in the stock column appeared to him, by the way, to have a pronounced effect on dust ejection.

As many furnace data were given in the Report, the record of this furnace to the present date (September 11) might be of interest :

	Tons.	
Total iron made. . . .	906,497	
Total coke used . . .	1,255,449	= 27·7 cwt. per ton.
Total ore, &c., used . . .	3,447,069	= 76·0 ,, ,, ,,
Total gross throughput . .	4,702,518	

Average ore/coke ratio = 2·75.

Mr. J. M. RIDGION (London) wrote that, on p. 91, the statement was made that " the expression log CO/CO_2 followed the temperature fairly closely at planes *G* and *J* " ; a plot was given (Fig. 35), showing the relationship for all the observations made. Statistical methods

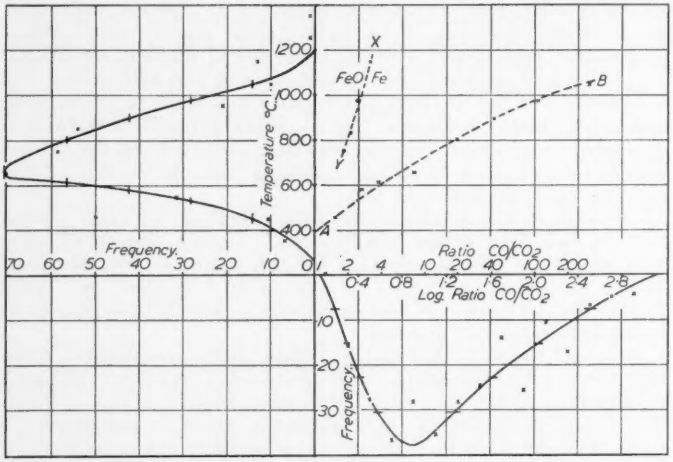

FIG. A.

were available for arriving at the most probable curve through the cluster of points, and the method employed by Sarjant [1] in another connection had been applied to Fig. 35. The method gave a smooth curve which was almost a straight line (Fig. A).

On this graph had been plotted CO/CO_2 ratios of gases in equilibrium with FeO and iron. The data used were taken from a paper by Professor Bone and his co-workers.[2]

[1] Sarjant, *Journal of the Institute of Fuel*, 1937, vol. 10, p. 357. *Iron and Steel Industry*, 1937, vol. 10, p. 561.

[2] Bone, Saunders and Rushbrooke, *Journal of the Iron and Steel Institute*, 1934, No. I., p. 47.

For all values of CO/CO_2 greater than those given by the curve XY, reduction should be complete when equilibrium was attained.

The extremely short time of contact between gas and ore in the shaft of the furnace was reflected in the wide divergence between the characteristic furnace curve AB and the equilibrium curve XY. Comparison of these two curves gave some indication of the departure from equilibrium of reactions in the blast-furnace.

Dr. STACEY G. WARD (Saltburn-by-the-Sea, Yorks.) wrote that it must be emphasised that, without the ready co-operation of the staff and men of the Appleby-Frodingham Steel Co., Ltd., it would not have been possible to carry out the tests described in the Report with any measure of success, and he would like to add to the acknowledgments in the Report his personal appreciation and thanks for all the help received.

Once a technique had been established, the sampling and testing operations ran fairly smoothly, and it might be of interest to record that, conversely to what might have been expected, the solid sampling presented the least difficulties, whereas the temperature measurement was far from easy.

As the work proceeded it became increasingly evident that the furnace was working—so far as the stack was concerned—in what might be termed a centro-annular fashion, with a hot central core, a hot zone near the inwall and cooler intermediate annuli, thus giving rise to the forms of the curves in Figs. 36 and 37 for the isothermal and iso-CO_2 lines within the stack. It must be emphasised most strongly that such lines of equal conditions could not be regarded as static; rather should each line shown be regarded as the approximate relative mean of its ever-changing position. Accordingly, the diagrams were useful in giving a *general* picture of average conditions, their accuracy being limited by the number of tests possible at each sampling point. While it was realised that absolute symmetry in working within the stack was unlikely, it was considered that, within the limits of accuracy imposed by the number of tests that could reasonably be made, and from the point of view of obtaining a *general* conception of the conditions, the furnace might be regarded as working symmetrically about the centre.

The work was commenced in an attempt to correlate certain laboratory findings of Professor Bone and his staff with actual works practice, but the variations observed were so great as to render correlation impossible at this stage. One of the difficulties of the blast-furnace operator was that he was unable, under existing conditions, to exercise control over the blast-furnace similar to that which could be achieved in laboratory experiments with materials from the same source. Apart from the scale of the operations, the difference was due mainly to the wide differences in the physical conditions of the reactants—the size and wide variations in size of the solids, the relative concentrations in adjacent zones of different

reactants and irregular size distribution—the latter giving rise to wide variations in the rates of gas flow in different parts of the furnace. It had, of course, long been recognised by blast-furnace operators that size distribution was a determining factor in furnace economy as well as in the smooth running of the furnace, and proposals had from time to time been made to obtain more uniform distribution. It was submitted that the results obtained on the Frodingham furnace indicated that the lack of uniformity across a horizontal plane in the stack was much greater than many operators would have expected, and that the effects of size segregation (coupled with the consequential chemical segregation) imposed at the stock-line by the charging gear were impressed on the materials within the stack to a great depth—at least to the top of the bosh.

Where materials over a wide size range were used and they were deposited into the furnace from a bell, segregation was bound to occur. The amount of segregation as well as the ultimate distribution would be dependent (apart from the actual size of the materials) to a certain extent upon the method of handling the materials before they reached the bell; the ordinary bell, however, would seem to exert the greatest effect on the ultimate distribution, which would depend upon, *inter alia*, the bell diameter, throat diameter, angle of bell, length of bell-drop, distance from the bottom of the bell to the top of the stock, amount of material on the bell and shape of the interior of the furnace top. One of two general types of stock-line contour was, therefore, likely to be produced in any furnace having the ordinary bell-charging device :

(*a*) having an inverted-**W** section, or
(*b*) having a **V** section.

In the case of the stock-line of the inverted-**W** type, the fines and smaller pieces fell almost vertically, while the larger pieces rolled down towards the depressions formed near the wall in one direction and towards the crater formed in the centre in the other direction. The furnace examined at Frodingham had the inverted-**W** type of stock-line and its effect was impressed throughout the stock.

In the case of a furnace having the **V** type of stock-line, the fines and smaller pieces were concentrated near the wall, while the larger pieces were found towards the crater in the centre. It would appear that such a condition existed in the Skinningrove furnace (No. 3) now being examined, where the tests so far carried out suggested that the furnace was working with a hot core, in such a manner that, across horizontal planes (at least in the upper part of the stack), the temperature decreased from the centre to the inwall.

In whatever way a furnace might be working, the gas flow at any point within the stack would be reflected in the temperature at that point as compared with the temperature of other points on the same plane. The gas flow would also depend upon the resistance offered by the materials in the stack, and where the resistance was

least (*i.e.*, where the larger pieces were concentrated) the flow would be greatest and the temperature highest. Accordingly, the gas distribution within the stack would, to a large extent, be dependent upon the size distribution of the stock; it would also be dependent to a large extent, especially in the lower parts of the stack, on the gaseous distribution at the main tuyeres and the bosh tuyeres (if any). Consequently, it was hoped that it would soon be possible to extend this investigation to include explorations within the tuyere zone of furnaces as well as within the bosh.

In this connection it was submitted that useful preliminary work might be carried out on a (not too small) model furnace, situated at a suitable works. With such a furnace work could proceed uninterruptedly and without interfering with ordinary works production, and it should be possible to obtain results which could be applied with advantage to full-scale practice, especially with regard to blast distribution, methods of charging and stock distribution, &c.

Dr. J. C Hudson (Birmingham) wrote that Mr. Hoskison had referred to a point which he himself had intended to raise, namely, that the inference to be drawn from Figs. 36 and 37 was that the isothermal lines and the lines of equal CO_2 content would be shown on horizontal sections of the stack as a series of concentric circles. It had appeared to him on purely scientific grounds that it was desirable to verify this inference by actual observation, and he was interested to hear Mr. Hoskison's opinion, based on practical experience, that in all probability considerable deviation from a regular distribution occurred in horizontal planes. In view of this fact, the Sub-Committee might consider the possibility in their future work of extending their observations to a study of the conditions in one or more horizontal planes of the furnace, although he appreciated that this would add materially to their work, which was already a matter of great experimental difficulty. The fact remained, however, that it would probably be wise to assume that the study of the conditions in a blast-furnace was a three-dimensional problem until the contrary had been shown to be the case.

Mr. F. W. Harbord, C.B.E. (Past-President, London), wished to congratulate Professor Bone and the Blast-Furnace Reactions Research Sub-Committee on the most valuable Report they had presented and to express his appreciation of their great skill and ingenuity in devising apparatus for sampling gas and solids and of the immense amount of labour expended in sampling and analysing such a large number of gas and other samples. He was particularly interested in the ore reduction results summarised in Table XIX. and shown graphically in Figs. 34A and 34B.

When considering the percentage of reduction at the different levels *A*, *D*, *G* and *J* across the furnace it must be remembered, in comparing these, that the samples were not taken at the same

time, or even on the same day, but with considerable intervals between them; thus between *D*1 [1] and *A* there was an interval of nearly seven months, and between *D*1 [1] and *D*5 an interval of nearly four months.

The best conditions would be to take samples at the different levels *A*, *D*, *G* and *J* at the same time or, say, within an hour or so, to eliminate as far as possible variables due to ore distribution, physical condition of the ore, variation in coke, &c. The writer fully realised the difficulties of sampling at four levels at the same time, as it would entail great expense for apparatus, platforms and increase of staff, and might interfere with the furnace operations to such an extent as to make it impossible. These remarks were not in any sense intended as a criticism of the experimental work but to suggest that great caution should be exercised before drawing conclusions as to the percentage reduction at the different zones even in respect to this particular blast-furnace, and to suggest that, so far as increased expenditure was concerned, it might be worth while to incur this and take samples at each zone at the same time, assuming that the working conditions permitted. This, of course, would only apply to the ore samples and gas taken at the same time, and not to the gas samples generally, which would be impossible owing to their large numbers.

In Table A the results for levels *D*, *G*, *J* and *A* from the wall to the centre of the furnace were tabulated, so that the variation from the wall to the centre could be directly compared and an average at each position shown.

Owing to the great variation in the results at the same distances from the furnace wall at each level, it would seem very unsafe to take averages, although these were given in the Table. Thus, at 2 ft. from the furnace wall the record varied in *D*1 to *D*5 from 93% to 53% of reduction; in *G* the variation was from 91% to 72% and in *J* 86% to 71%. Only one result was given for *A*, so that it was not possible to say what the variation would have been. At 3 and 4 ft. from the furnace wall the same general variation was shown (in the worst case, *J*, a variation from 24% to 63% being obtained); at 9 ft. from the wall in *G* there was a variation from 59% to 79% and in *J* 64% to 38%. These variations in samples taken from the same levels and at the same distances from the furnace wall were not surprising, but they were too great to permit of taking an average, and they emphasised the necessity of exercising great caution in drawing conclusions based on such variable results.

At zone *A*, 44 ft. below the stock-line, only one sample was taken, whereas four and five were taken respectively at *G* and *D*. Probably the Sub-Committee had some special reason for not taking more samples at the *A* level, but in view of the variations shown in the samples taken at other levels, it would have been very

[1] The numerals following the letters indicating the sampling levels refer to the groups of results, in serial order, contained in Table XIX. of the Report.

TABLE A.—*Percentage Reduction of Ore in the Blast-Furnace.*

Sampling Position.*	Distance from Inwall. Ft.																Average from Wall to Centre.	Average of all Determinations.
	0.	½.	1.	2.	3.	4.	4½.	5.	5½.	6.	7.	8.	9.	10.	11.	12.		
*D*1	...	89·0	...	92·4	89·9	...	88·8	...	82·7	...	...	...	...	...	...	...	88·56	73·6
*D*2	...	...	58·0	...	62·9	...	...	67·5	...	...	78·6	...	67·0	...	...	...	66·80	
*D*3	70·3	...	...	83·0	...	71·5	...	...	...	65·4	...	81·1	...	85·1	...	69·7	75·16	
*D*4	70·3	...	...	68·9	...	69·2	...	...	...	76·2	...	78·8	...	85·7	...	73·5	74·66	
*D*5	64·5	...	...	53·5	...	55·7	...	...	...	59·3	...	77·0	...	74·0	...	75·8	65·7	
Average :	68·4	...	...	74·5	76·4	65·5	...	...	...	67·0	...	79·0	...	81·6	...	72·3	...	
*G*1	90·2	...	...	96·6	...	88·9	...	...	...	76·3	...	78·0	...	...	...	...	86·0	76·3
*G*2	...	...	91·1	...	90·9	...	...	71·8	...	...	66·1	...	59·3	...	66·7	...	74·3	
*G*3	...	...	72·7	...	63·4	...	...	53·2	...	...	78·7	...	72·0	...	75·4	...	69·2	
*G*4	...	...	85·4	...	81·0	...	...	66·2	...	...	73·3	...	79·3	...	79·4	...	77·4	
Average :	...	...	83·1	...	78·4	...	...	63·7	...	...	72·7	...	70·2	...	73·8	...	...	
*J*1	...	...	86·9	...	24·5	...	...	19·7	...	...	46·8	...	64·6	...	59·6	...	50·3	49·8
*J*2	...	...	71·0	...	63·4	...	...	29·2	...	...	35·3	...	38·6	...	58·3	...	49·3	
Average :	...	...	78·9	...	43·9	...	...	24·5	...	...	41·1	...	51·6	...	58·9	...	...	
A. only one sample	...	...	...	88·5	...	88·4	...	...	...	87·8	...	87·1	...	90·4	...	...	88·4	88·4

* The numerals following the letters indicating the sampling levels refer to the groups of results, in serial order, contained in Table XIX. of the Report.

interesting to see to what extent the samples taken from this level on different days varied, especially as in the writer's opinion the percentage reduction at this zone just above the bosh was of special interest. Sample *D*1 gave almost identical results to *A*, and had the Sub-Committee relied upon the sample *D*1 alone, the deduction would have been drawn that the percentage reduction at *D* was practically the same as that at *A*, and, apart from the fact that the results shown at *A* were what might reasonably be expected, there was no reason for assuming the *A* results to be more representative of the *A* level than *D*1 was of the *D* level. In the curves shown in Figs. 34A and 34B, *D*1 was not included; was there any special reason for this? So far as one could judge, although this result was much higher than those for *D*2, *D*3, *D*4 and *D*5, it was a little higher than those for *G*1, where the samples taken from the wall to the centre gave an average of 86% reduction compared with 88·59% for *D*1 and 88·4% for *A*.

Based on the results, if an average were taken of *all* the results across the furnace at each level *D*, *G*, *J* and *A*, percentage reductions of 73·6% for *D*, 76·3% for *G*, 49·8% for *J* and 88·4% for *A* were obtained.

The average results at *J* gave 49·8% reduction and were, as one would expect, lower than the others, but the average of the *G* results, 76·3%, which were taken at 26 ft. below the stock-line, actually gave a higher result than the average at *D*, 73·6%, taken 35 ft. below the stock-line. As might be expected, *A* gave the highest reduction, 88·4%, but this was based on only one sample, and samples *G*1 and *D*1 were very nearly the same, *viz.*, 86% and 88·5%, respectively, showing that under certain conditions the reductions at *G* and *D* levels were the same as at the *A* level.

The Sub-Committee had refrained from drawing any conclusions, but if the above results truly represented the percentage reduction at different levels then 75% of the work was done at 26 ft. below the stock-line, and possibly more, and only 25% remained to be done between the 26-ft. level and the tuyere level. This might be the case, but the writer considered that much further evidence was required before it would be safe to assume this, even in respect of this particular furnace.

SUB-COMMITTEE'S REPLY.

Professor W. A. Bone, replying on behalf of the Sub-Committee, desired to express their gratification with the favourable reception accorded to the Report and their thanks to all those who had participated in its discussion.

Some speakers had expressed doubts about the solid samples, the accuracy of which was admittedly less than that of the gas

samples owing to the greater difficulty in getting truly representative solid than gas samples at any given region in the furnace; yet they were the best obtainable in the circumstances and there could be no doubt about their having been accurately analysed.

Mr. Hoskison's suggestion that the data on which the isothermal and iso-CO_2 diagrams were based "were a series of spot determinations taken over a very considerable period" and that "at any moment following the one at which they were taken an entirely different result might have been obtained" could not be passed unchallenged, for it was misleading. The data upon which the diagrams referred to were based were *not* "spot determinations," but (as stated on p. 90 of the Report) "proper statistical averages for the numerous temperature measurements and gas compositions at each sampling point," and the statistical expert to whom they had been submitted for independent examination and report had pronounced them as adequate for arriving at a valid general view of the actual furnace conditions. Also against Mr. Hoskison's surmise that while the diagrams in question might be valid for one half of the furnace, they were not so for the other half of it, might be cited Mr. Behrendt's testimony that from his knowledge of the furnace he had no reason to believe that another series of experiments, conducted at points diametrically opposite to those used, would have given results on the average very widely divergent from those obtained.

The concluding sentences of paragraph (7) on p. 94 of the Report, if read (as was intended) strictly in conjunction with the context, merely stated a relationship between observed facts and needed no qualification.

There would appear to be some justification for Mr. Harrison's remark that some other means of charging furnaces than the usual bell-and-hopper device would have to be devised if the marked irregularities, as regarded both temperatures and CO_2 contents, observed across a horizontal plane in the stack of a furnace were to be eliminated; presumably such desideratum would result in greater uniformity in, and better control of, the working conditions and therefore be conducive to greater fuel economy.

The detailed remarks of Dr. Becker and of Mr. Harbord and Mr. Ridgion about the progress of ore reduction in the furnace were much appreciated and would be borne in mind by the Sub-Committee. They bore upon what was probably the most difficult aspect of the investigation, about which the Sub-Committee hesitated to express any decided opinion until further evidence had been accumulated.

Mr. Harbord had also directed their attention (privately) to a misprint in a statement appearing on p. 97, line 16, of the Report, which should read: "the second ferric titre d gives the value $b + z + h$."

The Sub-Committee, while fully recognising the magnitude and

difficulty of their task, regarded this investigation as a substantial start towards its fulfilment, and were gratified by the support accorded to their proposed extension to other typical British smelting conditions. For undoubtedly a vast field remained to be explored before the results of such field tests could be co-ordinated ultimately with those of fundamental laboratory investigations, and the classical work begun by Lowthian Bell be completed.

FOAMED BLAST-FURNACE SLAG.

By T. W. PARKER, M.Sc., Ph.D., A.I.C. (Building Research Station, D.S.I.R., Garston, Herts.).

This Report was published as Special Report No. 19; it was presented at the Autumn Meeting of the Iron and Steel Institute held in Middlesbrough on September 16, 1937. The discussion and author's reply follow the summary below.

Summary.

An investigation was carried out on the suitability of foamed blast-furnace slag as a lightweight concrete aggregate.

Particular attention was paid to verifying that slags which normally "fall" on slow air-cooling are stabilised by foaming. A range of slag compositions was therefore used, of which the majority of the individual samples had a high lime content, such as would cause falling if the slags were slowly cooled in the normal way. Experimental foaming tests were made on these, and observations were made on the foamed products under a variety of weathering and storage conditions. Attempts were also made to accelerate any disintegrating effects by annealing and by water and steam treatments. No evidence of falling in these foamed slags was observed, and it is concluded that foaming stabilises falling slags, at least in the range of compositions examined (*i.e.*, up to lime contents of 50%).

Attention was also paid to the question of whether the contents of sulphur compounds in the foamed slags are likely to be at all deleterious when the material is used in concrete. No free sulphur as such exists in blast-furnace slag, but a certain amount is always present chemically combined as sulphide or sulphate. The two objects of the tests were to determine whether steel reinforcement in concrete would be affected by the sulphide, and whether the cement would be attacked by the sulphate. In agreement with the results of other investigators, it is concluded that the foamed slag concrete is not intrinsically corrosive to the steel; on the other hand, the protection afforded to steel by lightweight concrete, whether made with foamed slag or other lightweight aggregate, is not so complete as that given by heavy aggregates. An examination was made to determine whether sufficient sulphate is present in foamed slags to produce an expansion by reaction with the cement in the presence of moisture. A test was devised to determine the "available sulphate," on the assumption that only the sulphate in the surface layers of the aggregate would be reactive to the cement. The permissible limit of available sulphate, by the suggested method,

was assessed at 0·5%, this being based on the experience of the Building Research Station with other lightweight aggregates, and on long-period strength tests on foamed slag concrete. All but one of the samples had available sulphate contents below the permissible limit.

Tests were devised which are considered to be suitable for use in standard specifications for foamed slag.

A detailed account of the properties of foamed slag concrete, based on the results of tests at the Building Research Station, is in course of preparation and will be published elsewhere, but a summary of these results is included in the present publication. It is concluded that the strength of the concrete varies in a general way with the weight per cubic foot. On the whole, the materials examined gave concretes showing higher strengths than concretes made with other lightweight aggregates, although the weights per cubic foot were higher than those of the lighter types of lightweight aggregate. Such properties as thermal insulation, moisture movement, ease of plastering, &c., were comparable with those of the lighter types.

DISCUSSION.

Dr. T. W. PARKER, in presenting the Report, expressed his appreciation of the help given to him by blast-furnace managers on blast-furnace slags generally when he visited their works.

He called attention to an error on p. 28 of the Report. At the foot of that page, it was stated: "Concrete of about 115 lb. per cu. ft. was produced from mixes of cement and foamed slag in the ration of 1 : 3 by weight, and this mix had a compressive strength value at 28 days of 4900 lb. per sq. in. . . ." The error was that the proportion was not 1 : 3 by weight; it was actually 1 of cement to $1\frac{1}{4}$ of fine foamed slag to $1\frac{3}{4}$ of coarse foamed slag by volume. Although the proportions of the aggregate added up to 3, if one mixed those aggregates one would not actually obtain 3 parts, but about 2·65 parts. The weight ratio corresponding to this was 1 : 1·09. Similarly, the 1 : 6 figure referred to at the top of p. 29 was not a weight ratio but a volume ratio, and its true value should be 1 of cement to $2\frac{1}{2}$ of fine foamed slag to $3\frac{1}{2}$ of coarse foamed slag, corresponding to a weight ratio of 1 of cement to 2·2 of total aggregate.

Mr. G. H. JOHNSON (Kettering) said that the admirable Report which Dr. Parker had presented, being a record of fact, was not very suitable for purposes of discussion, but, arising out of it, he would like to enter a plea for some degree of rationalisation in the blast-furnace slag industry. It had been stated that foamed slag compared favourably with other lightweight concrete aggregates

in common use, and, further, that the foaming process resulted in a stable product even when applied to slags of high lime content, which normally disintegrated when air-cooled. There were possibilities in the process which might result in a market being found for slags which were at present dumped. It had been felt, however, by some of those who marketed most of their air-cooled slags, mainly slags from basic and foundry and forge iron production, which were now used for road-stone, that when the work in progress at the Building Research Station was completed, the best of their blast-furnace slag, which they knew to be a high-grade material, well able to compete with alternative materials, might be accepted as a heavy concrete aggregate under a British Standard Specification, probably accompanied by the necessity of its satisfying certain performance tests. Just how that was going to be done, remembering the primary function of slag as a reagent divinely appointed for the purification of metals, and carrying, of course, deleterious components which were well known, was not quite clear; but at any rate foamed slag such as had been described by Dr. Parker was an example of a *Controlled Product*, and anyone buying it would know just what he was getting and what might be expected of it. Until the work had proceeded further, with the sympathetic support of the industry, it seemed impossible to forecast just what further similar Controlled Products would be made available.

The PRESIDENT (Mr. Alfred Hutchinson) said that those who visited Skinningrove would see there a jetty which his father had built for commercial reasons. When doing so, it was found impossible to obtain satisfactory foundations under sea-water with the ordinary cement, and that led his father to take out a patent for making hydraulic cement about the year 1883. He used blast-furnace slag by the process of regulating the supply of water underneath a stream of slag passing along a trough, allowing sufficient to produce a double hydrated silicate the initial heat of which was enough to give a chemically dry product. Adding that to lime, he made his first hydraulic cement, and that enabled him to build the jetty. The product in those early days was called slag shavings, but was now known as foamed slag.

Whatever foamed slag might do as an aggregate for concrete, he was quite sure that it made by far the most excellent mortar that he had ever known. For many years after they stopped making the cement—they stopped it because the Westminster engineers in those days would not accept any cement made from blast-furnace slag—they continued to make foamed slag and to use it as a mortar; and he could give the assurance, after using it for many years in all the foundations and brickwork about their works, that he had never seen a wall in which it was possible to separate the individual bricks where they had been united by this

mortar. That showed the possibility of using foamed slag for mortar in the future, and he would direct the attention of the Blast-Furnace Committee to the possibility of exploiting that market for it.

AUTHOR'S REPLY.

Referring to Mr. Johnson's remarks, Dr. PARKER replied that it was agreed that material satisfying a British Standard Specification would probably be most acceptable to users, but it was doubtful whether a suitable specification for air-cooled slag could be drawn up at the present time. Research was in progress at the Building Research Station which might provide the necessary data when a specification was considered.

The remarks by the President, on the use of foamed slag in mortar, might be compared with the data in Table XIII. of the Report, from which it would be observed that the strength of foamed slag mortars increased more rapidly than that of similar sand mortars, this being attributed to the hydraulic properties of the foamed slag.

COMMUNICATION.*

By G. C. RICHER (Newport, Mon.).

A Note on the Influence of Grain Size on Magnetic Hysteresis.

Summary.

Much investigational work has been done in recent years on the influence of grain size on magnetic hysteresis; and although most observers are in agreement that, other things being equal, the hysteresis loss decreases as the grain size increases, it has not hitherto been found possible to formulate a general expression of the mathematical relationship between crystal size and the magnitude of the hysteresis effect.

In this Note, the suggestion is advanced that the difficulty in correlating the grain-number N with the hysteresis loss associated with the grain-size effect arises from the fact that the quantity N is a purely arbitrary number, which can only give a satisfactory indication of the true characteristics of a given crystal structure under certain rather restricted conditions—conditions which are not usually satisfied by the types of specimen which are commonly submitted to metallographic and magnetic measurement.

The fundamental physical conditions which govern the appearance and the magnitude of the grain-size hysteresis loss are discussed, and equations are formulated which appear to indicate that, by approaching future investigation of this subject from a new angle, there is a possibility that it will be easier to arrive at a more satisfactory correlation between the observed hysteresis loss and the pertinent magnitudes of the crystal structure under examination.

In recent years, much attention has been given to the question of the effect of grain size on the magnetic properties of iron and the iron-silicon alloys, the most important contributions to knowledge on the subject having been made by Yensen,[1] Yensen and Ziegler,[2] and Ruder.[3] (A list of references to relevant papers will be found at the end of this Note.)

The opinion of the majority of workers on this problem appears to be that, other things being equal, magnetic properties are improved as the grain size increases—that is, the maximum permeability is increased and the coercive force and the hysteresis loss are reduced. On the other hand, it has been affirmed that, under certain conditions, the reverse is the case (Goss[4]).

It is the purpose of this Note to review the whole question of the influence of grain size on hysteresis loss, not so much from the

* Received August 19, 1937.

experimental standpoint as from first principles, with the object of arriving at a conception of the mechanism of the problem which will make it possible either to effect some sort of reconciliation of the divergent views that have been expressed on the subject by different observers, or to frame a reasonably satisfactory explanation of the difficulty, to which Ruder has already referred, of correlating the available experimental data.

In the first place, however, it will be helpful to consider the relationship between grain size and hysteresis loss, as it presents itself in commercial practice in the case of 4% silicon transformer sheet steel, 0·35 mm. in thickness.

To obtain the necessary data, a number of samples were taken from sets of total-power-loss test strips. It was assumed that it is legitimate to calculate the hysteresis loss due to carbon, sulphur, &c.,

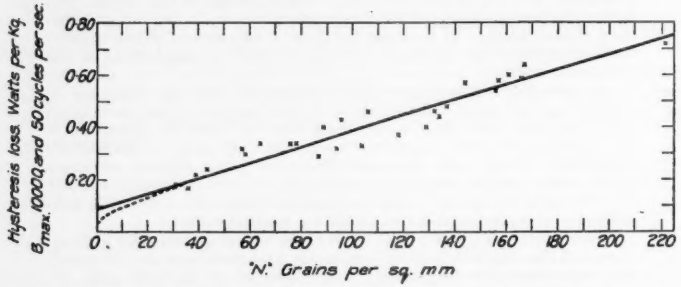

FIG. 1.—4% Silicon Transformer Sheet Steel; thickness 0·35 mm. Grain size plotted against hysteresis loss.

by utilising the information that Yensen has so very carefully collected on the influence of these adverse factors. The grain size hysteresis loss was then arrived at by deducting from the separated hysteresis component of the measured total power loss the hysteresis loss estimated to be due to the non-metallic impurities. The results are shown graphically in Fig. 1.

In this series of samples, the carbon content varied between 0·012 and 0·037%, and the sulphur content between 0·014 and 0·035%. The steel-making conditions, rolling conditions and heat treatment were comparable in all cases.

The grain count N used in the graph represents test-strip surface counts only, and it may be objected that it is not possible to give a complete picture of the experimental conditions unless the grain count across the section of the strips is also considered. The objection is valid, but examination of the cross-section of the test strips showed that throughout the series of samples the grains were reasonably equi-axed, and that no serious error is introduced by regarding the more metallographically convenient grain count on the

surface of the strips as reflecting with sufficient accuracy the true variation in average grain size.

It is obvious from Fig. 1 that, over this range of commercial samples, there exists a very well-defined relationship between the grain count N and the hysteresis loss estimated to be due to the grain-size effect. The relationship appears to be straightforwardly linear, with the solution

$$\text{Grain-size loss} = 0{\cdot}09 + 0{\cdot}003N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where the loss is expressed in watts per kilogramme at $B_{max.}$ 10,000, and a frequency of 50 cycles per sec.; or, more generally,

$$\text{Grain-size loss} = 135 + 4{\cdot}5 \text{ ergs per c.c. per cycle} \quad . \quad . \quad . \quad (2)$$

This result is in agreement with the simple linear relationship that Yensen has found to prevail in most of his recent results; but does it really represent the whole truth? What physical interpretation is to be associated with the statement that there is a simple linear relationship between the grain count N and the hysteresis loss due to the grain-size effect? In other words, *what is the physical significance of* N?

In an equi-axed polycrystalline structure, the quantity N is simply the measure of the number of grains per unit of surface or cross-sectional area counted on the screen of a microscope when a polished and etched specimen is submitted to metallographic examination. By itself, it represents nothing more than a convenient method of indicating the structural dimensions of a crystal system.

Now, suppose that on a cross-sectional micro-specimen the quantity N be taken literally at its "face" value, and that the physical interpretation sought for be assumed to consist in the statement that the hysteresis loss due to the grain-size effect is a function of the number of "cells" per unit of area through which the magnetising flux has to pass on the "honeycombed" structure revealed by the microscope; or, alternatively, that the hysteresis loss is a function of the "cell" perimeter per unit of area. But unless a very peculiar and non-existent type of rigidly rectangular crystal structure were involved, such statements would only be valid if the conditions were such that the magnetising flux wended its way through a continuous series of exactly similar honeycombed sections in its passage through the material under examination. That is, the internal structure of the specimen would have to be imagined as an aggregate of polyhedral tubes, each tube extending along the whole length of the specimen, the mean cross-sectional area of the tubes being equal to N^{-1}.

But this interpretation of the physical significance of N would become utterly meaningless if the magnetising flux were applied at right angles to the original direction, because, in such a "tubular" aggregate, a microsection taken across the new direction of magnetis-

ation would reveal no " cells " at all, but simply a system of parallel straight lines. Further, as can easily be seen by reference to Fig. 2, the distribution of these straight lines would vary by reference to the particular plane across which the microsection was polished and etched; so that any attempt to correlate this type of " microstructure " with the magnetic behaviour of the material would obviously be doomed to failure.

It is clear from Fig. 2 that, from the magnetic point of view, it is folly to hope to arrive at a correct conception of the physical meaning of N by considering only the plane section over which N is counted. Some guidance must, therefore, be sought from the fundamental conditions that give rise to the grain-size hysteresis effect.

It is generally accepted that magnetic hysteresis appears wherever there is discontinuity, distortion, or disturbance of the regular atomic space lattice. Now, assuming that a perfectly pure and

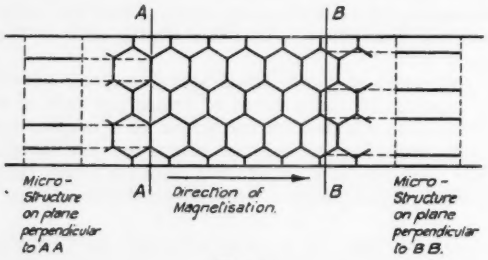

FIG. 2.

mechanically-unstrained crystal aggregate is under consideration, and disregarding for the present purpose the complication of " mosaics " or " crystallites," hysteresis may be expected to be associated with lattice disturbance or discontinuity at the crystal boundaries.

But in the interior of a crystal system, it seems necessary, where magnetic hysteresis is concerned, to differentiate between two types of lattice disturbance that may arise at such boundaries. There is the lattice discontinuity associated with *opposing grain faces*, and there is the lattice disturbance associated with *lines of angular grain junction*. This differentiation has not hitherto been insisted upon, but it does not appear to be justifiable to assume that the adverse effects on magnetic properties of these two types of lattice discontinuity will be quantitatively of the same order, or that the magnitude of those effects will permit of evaluation by reference to the same unit of measurement.

At the grain faces, there are only *two* crystal orientations to oppose each other, but at the lines of angular grain junction there

are *at least three*. The disturbance at the opposing grain faces will certainly be the more *extensive*; but the disturbance along the lines of angular grain junction will inevitably be the more *intensive*. And since the former type of lattice discontinuity is associated with *areas*, and the latter type with *lines*, there would seem to be every reason for anticipating that any attempt to estimate their respective effects on the hysteresis loss will necessitate differentiation in mathematical treatment. And if, as Ruder has suggested, it may be necessary to couple the effects of magnetostriction with those of simple lattice discontinuity when considering the origin of hysteresis, then the preceding argument would appear to derive an *a fortiori* application.

Now, in an equi-axed polycrystalline structure of N grains per unit of area (as ordinarily measured), the area per unit of volume of the opposing grain faces is a function of $\sqrt{N}$, and the length per unit of volume of the lines of angular grain junction is a function of N. If it be correct, therefore, to differentiate between the effect on the hysteresis loss of opposing grain faces and of lines of angular grain junction, a mathematical expression of the relationship between hysteresis loss and grain size would be expected to take the following form :

$$\text{Grain-size loss} = \alpha\sqrt{N} + \beta N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From the physical nature of things, α would also be expected to be fairly large compared with β, because α is associated with lattice disturbance over *areas*, whereas β is associated with lattice disturbance along *lines*; and, although the lattice disturbance along the lines may be locally the more intense, it certainly cannot be conceived to be as " factorially " forceful as the area effect.

This kind of relationship would go far to satisfy the order of facts as recorded by Honda and Kaya[5] in their experiments on the magnetisation of single crystals and of comparable material in the polycrystalline form. These observers found that " the hysteresis loss of a single crystal is very small, but that . . . it increases rapidly at first, and then more slowly but steadily with the increase of grain number. . . ." (Such an order of facts cannot possibly be satisfied by the acceptance of a simple linear relationship between N and the hysteresis loss.)

A conception of the mechanism of the problem has now been arrived at which involves two variables—one dependent on $\sqrt{N}$ and the other on N. But does this suggested presentation of the conditioning factors exhaust all the probabilities? So far, only the probable effect on the hysteresis loss of the *internal* conditions in a crystal aggregate has been considered. But *external* conditions must also play their part.

It has been commonly stated that there should be no hysteresis in a perfect single crystal. But is that statement justified unless the crystal is of infinite dimensions? If it be agreed that hysteresis appears wherever there is discontinuity of the space lattice, then

the external surface, even of a "perfect" single crystal, must necessarily have associated with it the adverse effects of lattice discontinuity. "In the interior of a crystal each atom is held in its place by forces due to surrounding atoms. Near the surface the surrounding is incomplete, and the atoms may be expected to break away from the normal pattern. There is, in fact, a surface layer in which the laws of the interior are modified" (Sir William Bragg[6]).

And this breaking-away of the atoms in the surface layer from the regular lattice pattern must inevitably mean that in dealing with the hysteresis loss in any given specimen, it is essential to consider, not only what happens in the interior, but also the relation between the external surface area of the specimen and its volume; and this applies both to a single crystal and to a polycrystalline aggregate.

Ruder apparently accepts the proposition that a single crystal should show no hysteresis, but he nevertheless finds it necessary to point out that, although it is customary to try and associate the hysteresis loss with the grain count or grain area, such attempts fail when the grain structure is large in relation to the dimensions of the specimen under examination. He has demonstrated that, under such conditions, it is possible, *without changing the apparent grain size*, to increase the hysteresis by merely reducing the *thickness* of the specimen. But he does not appear to admit a causal relation between this increase in the measured hysteresis loss and the increase in external surface area *per unit of volume* which results from the reduction in thickness; he refers only to the change in the experimental conditions produced by the reduction in the "dimension of the grain which is perpendicular to the flux," and stops short at the suggestion that, at any rate for large crystals, the grain *volume* appears to be more closely connected with the hysteresis loss than the superficial grain *area*.

In estimating the effect on the hysteresis loss of the external surface area per unit of volume, it will be obvious that there is no justification for applying the same numerical factor as that associated with the "internal" area of opposing grain faces. In the case of the external surface area, the hysteresis loss is not the effect of opposed crystal orientations, but simply the effect of lattice discontinuity at "free" crystal surfaces. For specimens of the same size and shape, however, this effect can be treated as constant for the same type of material, so that

$$\text{Grain-size loss} = c + \alpha\sqrt{N} + \beta N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For flat specimens, such as Epstein or Lloyd-Fisher total-power-loss test strips of electrical sheet material, where the other dimensions are large compared with the thickness, the external surface area per unit of volume will be very nearly inversely proportional to the thickness T; and in such cases, therefore,

$$\text{Grain-size loss} = \frac{k}{T} + \alpha\sqrt{N} + \beta N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where k is a constant for the particular type of material under examination. (For large-grained flat rings, Ruder's results show a rapid increase in hysteresis loss with decreasing thickness.)

In equations (4) and (5), however, none of the "constants" c, k, α, or β can be expected to remain unchanged for varying types of material. The physical interpretation of these "constants" must be that, per unit of volume, they are directly related, respectively, to the measure of the adverse effect on the perfect balance of "ideal" elementary magnetic systems of the particular type of lattice distortion or discontinuity associated in turn with unit area or unit length—as the case may be—of (1) the external "free" surface, (2) the "internal" surfaces at opposed grain faces, and (3) the lines of angular junction of the grains. It would obviously be quite wrong to expect that the magnitude of any of these effects would be the same for, say, electrolytic iron as for a 4% silicon-iron alloy.

Further, the magnitude of these effects will also be modified by the presence in the lattice of impurities such as carbon or sulphur; and Yensen has found, in fact, that the grain size hysteresis loss does depend on the actual amount of non-metallics present, quite apart from any adverse effect that such non-metallics may have on the magnetic properties in the *interior* of the crystals. (Fig. 1 does not, of course, indicate such dependence, because Yensen's conclusions on this point apply only to the effects of quantitative variation of impurities present either in true solution or as colloidal precipitates; and in the range of samples covered by Fig. 1 the quantities of non-metallics in "solution" would be virtually constant.)

Again, even for material of similar chemical composition, a general solution for the relation between grain size and hysteresis loss would not appear to be possible unless there exists either random orientation of the crystal structure, or a distribution of orientation which is substantially uniform throughout the range of specimens under examination. This latter condition would be expected to be satisfied by the range of samples covered by Fig. 1, which represents the results obtained on hot-rolled commercial transformer sheets; but if material of similar composition were to be rolled by a process involving heavy cold-reduction, so as to produce in the final structure a preferred orientation of the grains in a manner particularly favourable to easy magnetisation in one direction, then most certainly the measured hysteresis loss on such material would not be expected to conform to the curve. It is considerations such as these that appear to explain the results recorded by Goss.

In Goss's material, which was heavily cold-reduced, there is an abnormal variation in magnetic properties along different directions of magnetisation; but N will remain substantially the same in *all* directions, and it is therefore obvious that, with such material, the "constants" in equations (4) and (5) will require to be adjusted for such directional variations in magnetic susceptibility.

According to the hypothesis here advanced, it is clearly not possible unreservedly to accept the linear solution to the curve of Fig. 1 given by equation (1).

But actually, for values of N greater than 40, the line in Fig. 1 the apparent continuation of which gives the loss intercept of 0·09 for $N = 0$, is *not* the straight line of equation (1), but the graph of the equation

$$\text{Grain-size loss} = 0{\cdot}03 + 0{\cdot}012\sqrt{N} + 0{\cdot}0024N \quad . \quad . \quad . \quad . \quad . \quad (6)$$

a relationship which completely satisfies the conditions of equation (4). To satisfy equation (5) all that is necessary is to write

$$\text{Grain-size loss} = \frac{0{\cdot}0105}{T} + 0{\cdot}012\sqrt{N} + 0{\cdot}0024N \quad . \quad . \quad . \quad . \quad (7)$$

where T is the thickness in mm. of the range of samples involved (0·35 mm.). The dotted curve represents equations (6) and (7) for values of N less than 40.

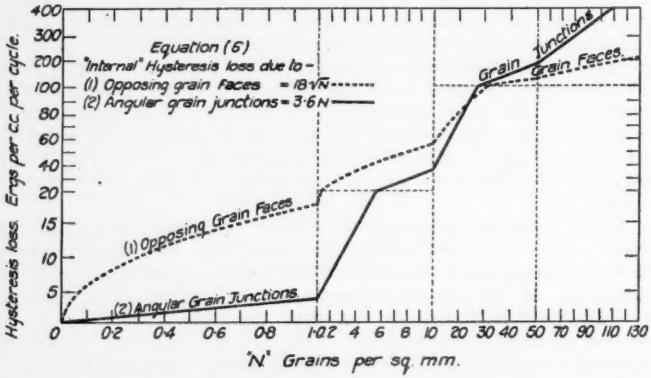

FIG. 3.—4% Silicon Transformer Sheet Steel; thickness 0·35 mm. Grain size plotted against hysteresis loss ($B_{max.}$ 10,000).

Over the range of grain size ordinarily met with in practice in commercial 4% silicon transformer sheet steel, a simple linear solution of the relationship between grain size and hysteresis loss can obviously be adopted with negligible error; but the experimental evidence strongly indicates that, when N is small, equation (6) will represent the truth much more nearly than equation (1).

Fig. 3 shows graphically the relative importance, according to equation (6), of the " internal " hysteresis loss due to the influence of opposing grain faces and of angular grain junctions. This graph illustrates the order of things revealed by the experiments of Honda and Kaya—that is, the influence of the grain faces ($f\sqrt{N}$) in the

ascendant when N is small, with a very rapid rate of increase in the hysteresis loss in the early stages; and the effect of angular grain junctions (fN) predominating as N becomes larger, but "toned down" by the progressive diminution in the rate of increase of the "grain-face" effect.

In his earlier work (1924 and 1930), Yensen accepted the $\sqrt{N}$ relationship for low carbon contents, and the linear relationship for higher carbon. Now, other things being equal, the lower the carbon content the greater is the grain size, so that these conclusions would also support the present hypothesis. In his later work (1935–36), Yensen adopts the simple linear relation even for very low carbon contents, but his samples were in the form of rings 1 in. in outside dia. by $\frac{3}{4}$ in. in internal dia. and 1 in. long, and only one end face was examined to determine N. Further, Yensen's curves do not extend beyond $N = 10$. Under such conditions, it is impossible, as Ruder has pointed out, for the "end-face" grain count to give a trustworthy indication of the interior grain structure. And when it is remembered that, over any narrow range of N, it is very difficult, on the basis of experimental data only, to decide whether a small portion of an apparently straight line is, or is not, subject to the influence of a component of the second degree, it becomes questionable whether Yensen's later conclusions are as near to the truth as his earlier findings. (This suggestion does not, however, invalidate the acceptance, for the purposes of Fig. 1, of Yensen's estimates of the adverse effects on the hysteresis loss of carbon and sulphur contents of the order there concerned.)

Reference has already been made to the apparently unjustifiable assumption that a single crystal should show no hysteresis. According to the present hypothesis, equation (4) can be applied to single crystal conditions by making $N = 0$. But, in this equation the first term c will still remain so long as the crystal is finite, and there would therefore be nothing surprising in the fact that, even in the case of very pure single crystals, there exists quite a measurable hysteresis loss. It should be noted, however, that in the case of single crystals of similar material, the term c cannot be expected to be invariable, because the quantitative effect of lattice discontinuity at the crystal surface will be influenced by the orientation of the crystal with respect to the direction of the magnetising flux. Ruder's results confirm this.

In certain cases it will be practically impossible to find a value for N that will correspond to any physical reality, and it is desirable once again to insist that the quantity N is given by a purely arbitrary method of estimating the structural dimensions of a crystal system. It is useful and convenient in many cases, but may be very misleading in others. For instance, take the case of a fine cylindrical wire, consisting of a string of crystals all of which are unbroken over the cross-section of the wire. What is the value of N?

Also, consider a particular example cited by Yensen in 1930.

He referred to a specimen composed mainly of three very large grains, giving a value of $N = 0{\cdot}004$. But at a magnification of 100 diameters " clusters of microscopic grains were observed here and there along the grain boundaries "; if, in this case, N had been accepted as meaning the *average* number of grains per unit of area counted over a plane microsection, it would have been necessary to write $N = 0{\cdot}5$ instead of $N = 0{\cdot}004$—a very material numerical difference. But Yensen very rightly rejected such an interpretation of N as being " unreasonable."

Such examples serve to emphasise that the equations previously given are meaningless unless the characteristics of the crystal structure make it legitimate to say that the value of N, as ordinarily measured, does provide a reasonably accurate indication of *the magnitude, per unit of volume, of the determinant physical quantities* —namely, the area of the opposing grain faces, and the length of the lines of angular grain junction.

The general form of equation (4) would be as follows :

$$\text{Grain-size loss} = k_1A_1 + k_2A_2 + k_3L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where

A_1 = the external area per unit of volume of the specimen;
A_2 = the area per unit of volume of the internal opposed grain faces; and
L = the length per unit of volume of the lines along angular grain junctions;

k_1, k_2, and k_3 being constants for *strictly comparable material.*

Equation (8) could, of course, be readily applied to the fine cylindrical wire, to Yensen's " cluster " specimen, or to the imaginary " tubular " structure discussed earlier.

It is freely conceded that the general hypothesis here outlined does not facilitate the derivation of any immediately applicable universal solution of the complex relationship between grain size and hysteresis loss; but, having regard to all the available evidence on the subject, it does seem to provide a reasonably satisfactory explanation of the difficulties inherent in any attempt to reconcile existing data, and to indicate a new angle of approach to the problem which may be of some service in the future.

In conclusion, the author wishes to express his thanks to the Board of Directors of Messrs. John Lysaght, Ltd., for their kind permission to publish this Note.

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ERRATUM.

SOME EXPERIMENTS ON THE INFLUENCE OF SILICON, PHOSPHORUS, AND MANGANESE ON NITROGEN-HARDENING CAST IRON.

By J. E. HURST (Darlaston).

A paper printed in the *Journal of the Iron and Steel Institute*, 1937, No. I., pp. 255 P–264 P, with Plates XX. and XXI.

Attention is directed to the fact that the blocks of micrographs (*b*) and (*c*) of Fig. 1 on Plate XX. were interchanged during printing; that is, to say, micrograph (*b*) now illustrates specimen *A*14 and micrograph (*c*) illustrates specimen *A*12.

OBITUARY.

His Excellency Dr. THOMAS GARRIGUE MASARYK, first President of the Republic of Czechoslovakia and one of the most outstanding figures in the post-war history of Europe, died at Lana Castle on September 14, 1937. He was eighty-seven years of age. Dr. Masaryk was born on March 7, 1850, at Hodonin in Moravia, and after leaving school became first an apprentice to a locksmith in Vienna, and later assistant to the blacksmith in his native town. It may be said that his great career really began when, at the early age of 15, he entered the Gymnasium at Brno. He supported himself by giving lessons and achieved distinction by his brilliance in examinations. As a result of differences of opinion with the authorities, he later left for Vienna; he took his doctor's degree in that city and became acquainted with Charlotte Garrigue, whom he followed when she returned to the United States of America and who returned to Europe in 1878 as his wife.

The next 13 years were spent as lecturer and professor in Vienna and Prague respectively. In the latter city he first came to notice as the future champion of Czech nationalism and as an interpreter of current political and social trends. Author of a number of books, the teachings he expounded and the constant social activities in which he engaged led to his entering the Austrian Parliament in 1891. He resigned his seat in 1893, but was re-elected in 1907. Owing to his strong political opinions and his championship of the Czech peoples, he was obliged to spend some years abroad; during his exile in England he held a lectureship at King's College, London. He returned to Prague in 1918 as President of the newly-formed Czechoslovakian Republic. He retired in 1935 after having been re-elected to the Presidency three times, during the whole period of which he worked untiringly to promote the well-being of his country.

It will be remembered that during the Autumn Meeting of the Institute in Czechoslovakia in 1930, the President and Members of Council were received in audience by Dr. Masaryk at his private summer residence at Topolčianky. The cordial welcome extended to the delegation and the hospitality accorded during their overnight stay at the Castle were deeply appreciated, and will long be recalled with pleasure.

Following the Autumn Meeting his Excellency honoured the Institute by accepting Honorary Membership. By his death the Institute has lost a valued Member, and his country a great leader.

HENRY COULSON BOND died on June 12, 1937, at his home at Wargrave, Berkshire. He was seventy-two years old. For a number of years he was the recognised leader of the tinplate industry

in South Wales, and for over 50 years was associated with Messrs. Richard Thomas and Co., Ltd., of which he was first secretary and afterwards Chairman, being in no small degree responsible for the very successful building up of the concern from relatively small beginnings. He was Chairman of the Conciliation Board of the tinplate industry, and in 1926 was elected President of the National Federation of Iron and Steel Manufacturers. Among the industrial companies with which he was associated may be mentioned Messrs. Pease and Partners, Ltd., Loughor Colliery Co., Ltd., the South Wales Tinplate Corporation, Ltd., the Swansea Navigation Collieries, Ltd., and the Whitford Steel Sheet and Galvanising Co., Ltd. He played an active part in the public life of Carmarthenshire and Llanelly, and was High Sheriff of the county in 1919–1920.

Mr. Bond was elected a Member of the Institute in 1900. In 1929 he was elected a Member of Council, and in March, 1936, became an Honorary Vice-President.

Don Serafin Ajuria y Urigoitia, managing director of Ajuria S.A., engineers and agricultural machinery manufacturers of Vitoria, Spain, died on March 3, 1937, after a long and painful illness. He was elected a Member of the Institute in 1936.

Frank Appleyard died in October, 1936, at the age of fifty-one. For over 36 years he was connected with Messrs. Davy Bros., Ltd., of Sheffield, and held in this company the position of engineer and works manager. He later became associated with the Audley Engineering Co., of Newport, Shropshire. Mr. Appleyard was elected a Member of the Iron and Steel Institute in 1922.

Sir John Audley Frederick Aspinall died at his home in Woking on January 19, 1937, at the age of eighty-five. He was intimately connected with the evolution of the present railway system in Great Britain. He was born in Liverpool in 1851, his father being Recorder of that city. After leaving Beaumont he became a pupil at the Crewe locomotive works of the London and North-Western Railway, studying first under Ramsbottom and afterwards under Webb. For some time he was assistant manager of the steel plant at Crewe, and in 1875 was appointed works manager of the Great Southern and Western Railway's shops at Inchicore near Dublin. From that date until his retirement from active work in 1926, he filled a succession of important offices in both an administrative and consulting capacity. Nor were his activities limited to railways; he always retained a keen interest in education and rendered Liverpool University, of which he was Associate Professor of Railway Engineering and Hon. D.Eng., no small assistance in establishing its Chair of Engineering. He was knighted in 1917. He was a Past-President of the Institution of Civil Engineers, of the Institution of Mechanical Engineers, of the

Institution of Civil Engineers of Ireland, and of the Junior Institution of Engineers. Sir John Aspinal was one of the oldest Members of the Iron and Steel Institute, having been elected in 1887.

WILLIAM RALPH BATES, of The Elms, Hatton Park, Wellingborough, died on December 15, 1936. Mr. Bates was a Member of the Institute, of which he was a keen supporter and the meetings of which he attended very regularly, for 34 years, having been elected in 1903.

Major ROBERT ALEXANDER BULL, M.A., died on July 29, 1936, at the age of sixty-three. Well known in this country through his contributions to technical literature, he was one of the foremost steel-foundry metallurgists in the United States of America. From 1914 to 1916 he was President of the American Foundrymen's Association, of which society he was an Honorary Member. He joined the Institute of British Foundrymen in 1922. Major Bull was elected a Member of the Iron and Steel Institute in 1911.

CHARLES SYMONDS CAMERON, Vice-President and Treasurer of the Dominion Steel and Coal Corporation, Ltd., Montreal, Canada, died on October 13, 1937. He was elected a Member of the Iron and Steel Institute in 1928.

Professor WILLIAM CAMPBELL, Professor of Metallurgy at Columbia University, New York, died at his home in New York on December 16, 1936. He was sixty years of age. Born at Gateshead-on-Tyne, he graduated from King's College, London, in 1892, and after two years' further study at Oxford and work as a research student under Roberts-Austen at the Royal School of Mines, London, he joined Columbia University to study under Howe in 1902. In 1903 he became a member of the American Institute of Mining and Metallurgical Engineers. He was appointed instructor in metallurgy at Columbia University in 1904, and became Howe Professor of Metallurgy in 1924. During the thirty-four years that he lived in the United States of America, Professor Campbell occupied many other important positions apart from his appointment at Columbia; he held the office of metallographist to the technologic branch of the United States Geological Survey, and was at one time a member of the Advisory Committee of the United States Bureau of Standards. During the World War he was metallurgist to the New York Navy Yard and became a Commander in the navy. His activities covered an extraordinarily extensive field; numismatist, philatelist, an excellent photographer and a landscape painter of considerable merit, he nevertheless still found time to maintain a heavy correspondence with innumerable past students and leaders in the study of all phases of advanced metallography. He was a Fellow of the Geological Society of London and of the Institute of Metals.

Professor Campbell was elected a Member of the Iron and Steel Institute in 1909.

FRED CHANTRY died in January, 1937, at his home in Sheffield at the age of fifty-two. He joined the staff of the Sheffield Climax Steel Co., Ltd., some 26 years ago, having previously been connected with Messrs. Samuel Osborn and Co., Ltd., of Clyde Steel Works, Sheffield. He became a director of the former company and retained this office until his death. He had been a Member of the Iron and Steel Institute for nearly 18 years, having been elected in 1919.

WILLIAM CLARK died on March 13, 1937, at the age of eighty-three. Born in 1854 at Mauchline, Ayrshire, his whole life was spent in the steel industry. In 1873 he took a position with the Steel Company of Scotland, and in 1875 had charge of a small wire mill at Brighouse, Yorkshire. Later, however, he returned to the Steel Company of Scotland, of which he eventually became manager. His association with the industry in Sheffield began in 1911, when he took the post of manager at Messrs. Vickers' Sheffield works; he was appointed a full director of the company shortly afterwards. He was the first Chairman of the Steel Makers' Association in Scotland, and a Past-President of the West of Scotland Iron and Steel Institute. Mr. Clark retired from active work in 1925. He was elected a Member of the Iron and Steel Institute in 1901.

HARRY AUGUSTUS COUVES died in London on March 25, 1937. He was sixty-two years old. His apprenticeship was served with Messrs. John Stewart and Co., Ltd., and his electrical training was received with Messrs. Siemens Bros., Woolwich. In 1906 he was appointed engineer of the Power Department of the Newcastle-upon-Tyne Electric Supply Co., Ltd., and later became general manager of the company. In 1934 he was elected a director. Mr. Couves was a member of many associations and committees dealing with the electrical industries, and also of the Institution of Mining Engineers, the Association of Mining Electrical Engineers, and the North-East Coast Institution of Engineers and Shipbuilders.

He was elected a Member of the Iron and Steel Institute in 1910.

WALTER JOSEPH DAVY died in May, 1937, after a short illness. After serving an apprenticeship at the locomotive works of the North-Eastern Railway Co., and at the works of Messrs. Bolckow, Vaughan and Co., he became a partner in Messrs. Winder Bros., of Sheffield. Subsequently he became associated with Messrs. P. R. Jackson and Co., Ltd., of Manchester, eventually becoming Chairman; he retired from this position in 1932. Among many other of his interests may be mentioned directorships of Messrs. J. and G. Wells, Ltd., of Eckington and of Messrs. David Brown and Sons, Ltd., of

Huddersfield. He was also Chairman of Messrs. T. B. and W. Cockayne, Ltd., of Sheffield.

He became a Member of the Iron and Steel Institute in 1903.

LÉON DELADRIÈRE, a director of l'Association des Industriels de Belgique, died on October 16, 1936. He was elected a Member of the Institute in 1931.

GUILLAUME DANIEL DELPRAT, C.B.E., died on March 15, 1937, at Toorak, Victoria, Australia, at the age of eighty. Born in Holland in 1856, he went to Scotland when he was sixteen, and served an apprenticeship there in engineering. Following his leaving Amsterdam University, he occupied a number of posts in mining companies, and in 1891 became a consulting engineer in London. His association with the Broken Hill Proprietary Co., Ltd., began in 1897, when he became assistant to the then general manager; in 1899 he was appointed general manager, and held this office until 1921, when he retired from active work.

His fame rests on two great achievements: The successful application of the flotation process to the recovery of zinc, lead and silver from slimes resulting from the concentration process, and the part he played in the development of the Australian iron and steel industry. In 1915 the Newcastle Steel Works, which he had been so instrumental in creating, was declared open by Sir Ronald Munro Ferguson, then Governor-General of Australia.

His signal successes were rewarded in 1918, when he was made a C.B.E., and in 1935, when he was awarded the Australian Institute of Mining and Metallurgy Medal for outstanding service in these fields; the honour was instituted in 1935, and he was the first to receive the distinction. In the same year he was made an Honorary Member of the American Institute of Mining and Metallurgical Engineers.

He was elected a Member of the Iron and Steel Institute in 1917.

Sir JOHN DEWRANCE, G.B.E., died at his home in Thetford, Norfolk, on October 7, 1937, at the age of seventy-nine. Born at Peckham in 1858, he was educated at Charterhouse and King's College, London. Researches on the corrosion of steam boilers, carried out after he had left King's College, won for him the Watt Gold Medal and a Telford Premium of the Institution of Civil Engineers. His achievements in engineering, both as a technical man and as an administrator, were remarkable. He held over a hundred patents for engineering inventions, and was head of his own firm of Messrs. Dewrance and Co., Engineers. In 1899 he was elected Chairman of Messrs. Babcock and Wilcox, Ltd., and held this post until he retired in July, 1937; among other companies of which he was a director were Deal and Walmer Coalfields, Ltd., Kent Coal Concessions, Ltd., and South-Eastern Coalfield Extension,

Ltd. His skill in administration was amply demonstrated during the early years of the post-war period, when for six years he was President of the Engineering and Allied Employers National Federation. In 1923 he was elected President of the Institution of Mechanical Engineers, and from 1926 to 1928 was President of the Institute of Metals. He was also a member of the Institution of Civil Engineers.

He never ceased to advocate the cause of research; for many years he was on the General Board of the National Physical Laboratory, Chairman of the British Cast Iron Research Association, and a member of the Engineering Research Board and of the Commerce Degrees Committee of the University of London. In 1920 he was made a K.B.E., and was promoted to G.B.E. in 1928. His membership of the Iron and Steel Institute dated from 1905. By his death the engineering world has lost a great leader.

Ernst Werner Hafels died at his home in Wimbledon on September 4, 1937. He was forty-five years of age. He had resided in England since 1925, and for the last nine years had represented the firm of Demag, Duisburg, in this country. Among his more recent activities were those in connection with the erection of the new steelworks for Messrs. Guest Keen Baldwin Iron and Steel Co., Ltd., in South Wales. Mr. Hafels was elected a Member of the Iron and Steel Institute in 1936.

Lieutenant-Colonel Edward Douglas Blake Johnson, M.C., T.D., died on July 5, 1937. Colonel Johnson was surveyor for the Manvers Main Collieries, Wath-on-Dearne, but retired on account of ill health. He was elected a Member of the Iron and Steel Institute in 1936.

Dr. Frederick C. Langenberg, Vice-President in charge of research of the United States Pipe and Foundry Co., East Burlington, New Jersey, died on April 4, 1937, at the age of forty-seven. A graduate of Ohio State University and Harvard University, he later became instructor in metallurgy at the latter institution, but in 1915 resigned to take the post of metallurgist at the Watertown Arsenal. Eleven years later he became associated with the Climax Molybdenum Co., from which, three years afterwards, he went to take charge of research at the Burlington plant.

Dr. Langenberg was an active member of many technical associations and was the recipient of numerous awards from engineering societies for achievements in metallurgy; he was awarded a Carnegie Research Grant by the Iron and Steel Institute in 1921, and the Henry Marion Howe Gold Medal by the American Society for Metals in 1926. He contributed several papers to the *Journal of the Iron and Steel Institute* and was elected a Member in 1927.

His Excellency SALOMON ARVID ACHATES LINDMAN met his death in an airplane accident on December 9, 1936. He was seventy-four years old. Born in 1862 at Osterby, he served for 10 years in the Swedish Navy, retiring with captain's rank in 1892 to join his father in business. Politics, however, offered him greater attraction than business, and he soon attained distinction as a member of the Swedish Government. In 1906 he formed his first Cabinet; a moderate administration resulted. His interest in naval matters was maintained in spite of the demands made upon him by his political duties, and in 1907 he was promoted to Rear-Admiral on the Reserve List. When he returned to office again in 1917 he filled for some time the post of Foreign Minister. In the years which succeeded he continued his political activities and interested himself wholeheartedly in safeguarding the traditional institutions of his country. He formed his second administration in 1928. His Excellency was a Member of the Institute for more than 37 years, having been elected in 1898.

Colonel ALEXANDER MCBEAN, D.L., J.P., died on February 16, 1937, at his home in Tettenhall, aged eighty-two years. His name is noted for its long association with the iron and steel trade of the Midlands, with which he had been connected since 1873. In 1881 he founded Messrs. Alexander McBean and Son, iron and steel merchants of Wolverhampton, and became later a director of blast-furnace and mining companies in Northamptonshire; he was a prominent figure in iron and steel circles in many parts of the country. In Wolverhampton he took an active interest in all phases of public life, and was a member of the Town Council from 1890 to 1902, during which period he was Mayor (from 1897 to 1898) and for four years an alderman. He was the senior magistrate of the borough, and from 1933 a Deputy-Lieutenant for Staffordshire. The Volunteer Movement in that county owed much to the active interest which he took in its well-being; he became a colonel of the third Volunteer Battalion of the South Staffordshire Regiment and was awarded the Volunteer Decoration in 1903.

Colonel McBean ranked among the older Members of the Iron and Steel Institute, having been elected in 1894.

THOMAS POLLOCK MACNAB died in January, 1937. He was in his sixtieth year, and for many months had been seriously ill. He was proprietor of Messrs. Macnab and Co., Ltd., foundry equipment manufacturers, and had been a Member of the Iron and Steel Institute since 1902.

IAN SAMUEL OSBORN, B.A., died on December 19, 1936, after a short illness. He was thirty-six years of age.

The eldest son of Mr. F. M. Osborn, a director of Messrs. Samuel Osborn and Co., Ltd., he was educated at St. Anselms, Bakewell,

Ley's School, Cambridge, and Christ's College, Cambridge, where he gained an honours degree in engineering. After studying the practical aspects of engineering at the works of Messrs. Davy Bros., Ltd., Sheffield, he entered his father's firm, of which he became a director in 1927. He was more particularly associated with the steel foundry, where he acted as personal assistant to the Chairman of the company.

Mr. Osborn was a Member of the Institute of British Foundrymen and was elected a Member of the Iron and Steel Institute in 1925.

ARTHUR HUNGERFORD POLLEN, M.A. (Oxon), died on January 28, 1937, at the age of seventy. Educated at the Oratory School and Trinity College, Oxford, he acquired considerable reputation as a speaker on naval subjects. He was called to the Bar in 1893 and entered Parliament in 1895. Prior to the war he took an active interest in the development of fire-control systems for naval guns, and invented a special system which was widely adopted. His business interests were very wide; in 1927 he became Chairman of Linotype and Machinery, Ltd., and in 1932 was elected to a similar office in the Birmingham Small Arms Co., Ltd. At the time of his death he was a director of the latter company, of Follsain Metals, Ltd., the Follsain Syndicate, the Daimler and Lanchester Motor Companies and of Messrs. William Jessop and Sons, Ltd. He was elected a Member of the Institute in 1936.

DAVID RICHARDS, J.P., died in August, 1937, at his home in Ammanford at the age of eighty-four. After working for two years at the Pontardawe works of Messrs. W. Gilbertson and Co., Ltd., he built and managed for some time the Glenamman Tinplate Works, and in 1884 became part proprietor of the Dynevor Tinplate Works. He eventually assumed entire ownership of this last concern, and retained his interest in the business until 1919. For many years he was a prominent member of the South Wales Tinplate Association and for a considerable period acted as Assessor for the Tinplate Pool. In 1921 he became High Sheriff of Carmarthenshire.

Mr. Richards was elected a Member of the Institute as far back as 1889.

Dr. Phil. h.c. AXEL SAHLIN died on June 10, 1937, at the age of eighty-two. Dr. Sahlin was born in Sweden in 1855, and after graduating from the Technical University of Stockholm in 1877 travelled to the United States of America, where he held important positions at different iron and steel plants for many years. In 1897 he returned to Europe, and later became general manager of the Millom and Askam Hematite Iron Co., Ltd. From 1903 to 1914 he was a partner in the firm of Messrs. Julian Kennedy-Sahlin and Co., Ltd., of London and Brussels. In 1915 he formed with old associates the International Construction Co., Ltd., consultants in engineering work

to the iron and steel trade. Dr. Sahlin was connected during the course of a long life with the construction and operation of iron and steel manufacturing plant in the United States of America, India, and every important producing country in Europe. In 1921 he retired from active work with the International Construction Company and settled in Monte Carlo.

A strong supporter of the Institute and a regular attendant at its Meetings, Dr. Sahlin had also contributed papers to the *Journal*. He was elected a Member in 1900.

WARRINGTON FINLAY SLATER died on November 19, 1936, at his home in Shatton, near Bamford, Derbyshire, at the age of forty-seven. He entered the firm of Messrs. Dunford and Elliott, Ltd., steel and cycle manufacturers of Sheffield, 31 years ago as an office-boy, later becoming first manager and then general manager of the company in July, 1934. He travelled extensively both in England and on the Continent on behalf of Messrs. Dunford and Elliott. His social activities included work in connection with the Scout Movement in the Hope Valley. He was elected a Member of the Iron and Steel Institute in 1936.

G. B. R. TAVERNER died suddenly on May 13, 1937. Having served his apprenticeship as engineer with Messrs. Vickers, Ltd., of Erith, he later worked at the Weymouth and Fiume factories of the Whitehead Torpedo Co., Ltd., and with Messrs. James Chesterman and Co., Ltd., of Sheffield. After returning from active service in 1919 with the rank of Major, he formed in 1923, in conjunction with Mr. T. M. Willis, British Pigirons, Ltd., of which, at the time of his death, he was managing director. His foresight and initiative went far to establish the success of the company's business both in England and abroad. A firm believer in technical research, he himself was a member of the Institute of British Foundrymen, while his firm was a member of the British Cast Iron Research Association.

Mr. Taverner was elected a Member of the Iron and Steel Institute in 1926.

GEORGE THOM died in February, 1937, at the age of fifty-five. For nearly fifteen years he was works manager of the Lanarkshire Steel Co., Ltd., and in 1935 was appointed general manager of the company. Mr. Thom was a Vice-President of the West of Scotland Iron and Steel Institute, and a Member of Council both of the British Iron and Steel Federation and of the Scottish Steel Makers' Association. He was elected a Member of the Iron and Steel Institute in 1921.

THOMAS WILKINSON WILLIS died on September 10, 1937. He was actively interested in the welfare of Sheffield's industries and played a prominent part in their affairs; the whole of his life was

spent in the steel and tool trades in that city. His career began with Messrs. Sanderson Bros. and Newbould, from whom he went to Messrs. Joseph Ashforth and Co., and later to Messrs. Thomas Firth and Co., Ltd., of which firm he was manager of the Tinsley Works for over 20 years. In 1911 he became works director of Messrs. Sanderson Bros. and Newbould and retained his seat on the Board after his retirement in 1930. He was President of the Saw Manufacturers' Association from 1918 to 1935, and President also of the High Speed Steel Hacksaw Blade Association for eight years, besides occupying a similar position in numerous other industrial and technical organisations in Sheffield.

His death closes an association with the Iron and Steel Institute of over forty-six years, for he was elected a Member in 1890.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

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The Editor has been assisted in the preparation of this Survey by R. Elsdon, Librarian of the Institute.

REFRACTORY MATERIALS

A Study of Chrome-Alumina Bricks. Pt. I. T. R. Lynam and W. J. Rees. (Transactions of the Ceramic Society, 1937, vol. 36, Mar., pp. 110–132). It is shown that alumina added in the form of either calcined alumina or calcined Indian bauxite leads to certain improvements in chrome products. It was observed that the addition brought about a higher mechanical strength at high temperatures, and that the bond became more viscous with increase in bauxite content. This was indicated by the refractoriness-under-load tests and the high-temperature tensile tests. The best results obtained with regard to mechanical strength at high temperatures were the mixes containing the coarser-grained bauxite batch; this was probably due to the grog effect of the larger grains. The results indicate that the grading of the bauxite used is of great importance, as this controls the amount of melt formed as a result of chemical reaction. The slag test results indicate that the addition of more than 50% of bauxite decreases the resistance to slag attack. The reversible thermal expansion tests show that the addition of calcined Indian bauxite to the chromite used decreases the temporary thermal expansion. This supports the spalling test, which indicates that the addition of bauxite decreases the spalling tendency. The results of microscopical examination show the growth of needle-like crystals in the high-bauxite mixes fired at 1610° C. The chromite grains are decomposed, and it seems possible that the needle-like crystals are corundum. The results also indicate that the Cr_2O_3 is replacing the Al_2O_3 in the crystal formation.

A Study of Chrome-Alumina Bricks. Pt. II. T. R. Lynam and W. J. Rees. (Transactions of the Ceramic Society, 1937, vol. 36, Mar., pp. 133–136). A further series of bricks was prepared using high-grade Turkish chrome ore and Demerara bauxite. Observations made during the manufacture and service trials of these test-bricks are given. Reviewing the results obtained in Parts I. and II. of this investigation, it seems rather conclusive that the drastic conditions to be met in the basic open-hearth furnace are too severe for a chrome-bauxite brick. The refractoriness-under-load test in both the preliminary and works trial experiments indicated a rather low "start-to-fail" point with a long viscous range, the actual highest temperature being 1430° C. for the laboratory trials and 1370° C. for the manufactured bricks. It was thought that the viscosity would be great enough to more or less mask this low start-to-fail point; the service trials, however, show that this is not so. The trials in a tin-smelting furnace indicate that these bricks would probably give good service under conditions which are

less severe, especially from the temperature standpoint, than those met with in the basic open-hearth furnace.

Mixtures of Chromite and Grecian Magnesite. Pt. I. T. R. Lynam and W. J. Rees. (Transactions of the Ceramic Society, 1937, vol. 36, Mar., pp. 137–151). Chrome and magnesite are so frequently used in contact with each other in steelworks practice that it was thought desirable to investigate thoroughly the chrome-magnesite series. It was observed that the mechanical strength at high temperatures is gradually improved with an increase in magnesite content, and that the 50/50 mix has a fail point equal to that of the calcined Grecian magnesite in the tensile test. All the mixtures had a refractoriness higher than Cone 32, and were highly resistant to slag action of a very basic nature. The curves obtained in the reversible thermal expansion test indicate quite definitely that a gradual increase in temporary expansion is brought about with an increase in magnesite content, so that the troublesome characteristics of magnesite due to its high temporary expansion may be modified by the addition of chromite without sacrificing any other good qualities. The slight friability observed in the laboratory trials was greatly intensified in the test bricks, using coarse-grained calcined Grecian magnesite batch. This friability was less evident in the test bricks using the finer-ground calcined Grecian magnesite batch, and was still further decreased by the use of dead-burned Austrian magnesite, presumably owing to the greater content of impurities. The laboratory tests introducing felspar as a flux indicate that the addition of 2·5% of felspar to the 50/50 and 75/25 magnesite-chromite batches does overcome this friability without decreasing the mechanical strength at high temperatures to any marked extent.

Mixtures of Chromite and Grecian Magnesite. Pt. II. T. R. Lynam and W. J. Rees. (Transactions of the Ceramic Society, 1937, vol. 36, Mar., pp. 152–172). The results obtained in this part of the investigation substantiate the conclusions already drawn, that the addition of magnesite to a chrome brick improves its durability and mechanical strength at high temperatures. The tests and trials on the chrome-magnesite bricks containing 10% of added talc-concentrate have proved to be interesting and satisfactory. This part of the investigation has revealed the necessity for higher temperatures of burning in order to bring about the necessary conversions and changes in the brick. The addition of the talc-concentrate to the 75/25 chrome-magnesite mix, together with higher temperature treatment (1560° C.), has produced a test brick of high mechanical strength at high temperatures, having a uniform distribution of forsterite throughout the brick. This uniformity of distribution is an important factor, as was illustrated by the chrome-magnesite brick of German manufacture, in which a large proportion of forsterite had been developed, but not uniformly, resulting in local concentrations of a crystalline bond which was

possibly responsible for the friability observed in this brick. Unfortunately, it has not been possible to subject a sufficient number of the test bricks to the higher temperature required, to enable a service test to be carried out with them. However, the test bricks refired at a higher temperature in the silica kiln are giving very good service, and it is possible that the desired changes are taking place in the brick during use.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group B, "Inorganic Materials," were the following on refractories:

E. AZZARELLO and F. ABRAMO: Chemical analysis of refractory materials.

S. M. PHELPS: Comments on the present status of the testing of refractory materials.

Minerals Formed by the Reaction of Open-Hearth Slags with the Dolomite Hearth Bottom at High Temperatures. B. Pines and G. Kushta. (Stal, 1936, No. 7, July, pp. 47–59). The authors have investigated the reaction of dolomite with open-hearth slags at high temperatures, (*a*) by laboratory experiments and (*b*) by analysing samples from the hearth. The investigation includes X-ray analysis, analytical determination of the free CaO, petrographic analysis and determination of the refractoriness. Two kinds of slags were used in (*a*), with 20% of FeO and with 9% of Fe_2O_3. Mixtures of 5 to 50% of slag with 95 to 50% of dolomite were heated to 1380° to 1650° C. The minerals formed were Ca_2SiO_4, $Ca_2Fe_2O_5$, $MgAl_2O_4$, $MgFe_2O_4$ and $MgCaSiO_4$. Free MgO (periclase) was always present; with less than 20% of slag free CaO also occurred. Spinels were present with less than 30% of slag. Ca_2SiO_4 was present in the β-form; this form is not stable at low temperatures and goes slowly over to the γ-form. This process causes the disintegration of the dolomite hearth bottoms. The petrographical investigation showed that the grains of CaO and MgO are cemented by the silicates and spinels; this explains the primary hardening of the hearth bottoms by the actions of slags. The agglomerations formed by this reaction are refractory even up to 1880° C. The wear of the hearth bottom is caused by a continued reaction with the slags, which converts the dicalcium silicate and ferrite into the monocalcium compounds, which fuse at low temperatures and are washed away by the slags. (In Russian).

Modern Refractories for the Steel Industry. L. J. Trostel. (Iron and Steel Engineer, 1937, vol. 14, Mar., pp. 24–35, 46). The author reviews the important effect on the properties of refractory materials of improved methods of manufacture. He describes the characteristics of the chief refractories available for steelmaking, and outlines some applications of high-duty refractories in blast-furnaces, stoves, hot-metal cars and ladles, mixers, basic open-hearth furnaces, soaking-pits and heating furnaces.

FUEL

Propane and Butane have Specific Value in Production of Luminous Flames. W. Z. Friend and E. Q. Beckwith. (Industrial Heating, 1937, vol. 4, Mar., pp. 187–191, 196). The authors discuss the advantages of luminous flame gases for use in forge furnaces, glass-melting and annealing furnaces, with special reference to propane and butane.

Gas Burners for Heat-Treatment Furnaces. (Metallurgia, 1937, vol. 15, Mar., pp. 155–156). Illustrated particulars are given of Gako burners for the use of blast-furnace gas, coke-oven gas and producer gas.

Power Plant at the New Karabuk Iron and Steel Works, Turkey. (Fuel Economist, 1937, vol. 12, Feb., pp. 167–169). The scheme for the erection of an iron and steel works at Karabuk, Turkey, includes not only blast-furnaces, steel-making plant and rolling mills, but also a pipe foundry and various other units. Particulars are given of the power plant which will serve these works.

Turbo Alternator Units at Granite City Steel Co. C. C. Jordan. (Blast Furnace and Steel Plant, 1937, vol. 25, Mar., pp. 296–298, 302). The turbo-alternators in operation at the plant of the Granite City Steel Co., for the generation of electric power, are described and illustrated.

Fuel Briquetting. R. A. Strong, E. Swartzman and E. J. Burrough. (Canada, Department of Mines and Resources, Mines and Geology Branch, 1937, Report No. 775). The authors present an outline of the fuel-briquetting industry, the information given being meant primarily for those interested in the history, the present status and the possibilities of fuel briquetting in Canada. The results of recent briquetting tests conducted at the Fuel Research Laboratories of the Department of Mines are included. A comprehensive review of the patent literature is included in an Appendix.

Recent Developments in the Construction of Coke-Oven Machinery. H. C. Wood. (Gas World, 1937, vol. 106, Mar. 6, Coking Section, pp. 17, 36). Particulars are given of recent installations of coke pushers, coal-charging hoppers and coke-quenching cars.

Recent Developments in German Coking Practice. A. Thau. (Gas World, 1937, vol. 106, Mar. 6, Coking Section, pp. 26–30). A review of developments in the design of German coke-ovens and coke-oven machinery.

Carbonising Properties and Petrographic Composition of Millers Creek Bed Coal from Consolidation No. 155 Mine, Johnson County, Ky., and the Effect of Blending Millers Creek Coal with Pocahontas Bed and Pittsburgh Bed (Warden Mine) Coals. By A. C. Fieldner,

J. D. Davis, R. Thiessen, W. A. Selvig, D. A. Reynolds, G. C. Sprunk and C. R. Holmes. (United States Bureau of Mines, 1937, Technical Paper No. 572). The authors present the results of the chemical, physical and microscopic examination of coals from the above-mentioned districts, and give the yield and quality of gas, coke and by-products obtained on carbonisation.

Low-Temperature Coke-Ovens. A. Thau. (Glückauf, 1937, vol. 73, Mar. 20, pp. 264–268). After mentioning a number of German types of low-temperature coke-ovens, the author describes three with which experiments have been carried out in England (the Cellan-Jones, Lecocq and Kemp ovens) and discusses the results obtained. He concludes with a note on the economics of the Cellan-Jones coke-oven.

Continuous Distillation Plant for Road Tar. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Mar., pp. 37–41). Illustrated particulars are given of the layout and equipment of the Clayton continuous tar-distillation plant for the manufacture of road tar in operation at the Tudhoe Iron Works of the Weardale Steel, Coal and Coke Co., Ltd. Operating results are included.

The Determination of the Real Specific Gravity of Coke. J. Hiles and R. A. Mott. (Fuel in Science and Practice, 1937, vol. 16, Mar., pp. 64–71). It is apparent that the use of either organic liquids or wetting agents with water is liable to give abnormally high results for the real specific gravity of coke, by the formation of a condensed layer of liquid on the solid surface. Since organic liquids in general have a much higher coefficient of expansion than water, and require much more careful temperature control, it is concluded that their use is not to be recommended, and that the higher results obtained with their use are misleading. Water is not liable to give a condensed layer on the surface of coke, and, since its coefficient of expansion is low, it is the most suitable liquid to use. All closed pores are opened by crushing coke to −60 mesh, and there is no necessity to use coke more finely ground than this. Air is readily adsorbed on the surface of coke, and the liquid used for the determination of the specific gravity of coke should be freshly boiled before use. Vigorous boiling is helpful in displacing air in the specific-gravity bottle, and the use of a glycerine-water bath to enable the water in the specific-gravity bottle to boil at 100° C. under a reflux condenser is advantageous, and gives the more complete elimination of air. Temperature control is facilitated by the use of a stirred thermostatically-controlled bath.

Testing the Mechanical Properties of Coke. J. O. Gabinsky and S. I. Badanova. (Fuel in Science and Practice, 1937, vol. 16, Mar., pp. 85–92). An English translation of an article from the Russian periodical, Coke and Chemistry, 1936, No. 8. The paper is devoted to a study of the geometrical sizes of coke pieces, and the data obtained are used to explain the methods to be adopted for testing the mechanical properties of coke, and to indicate

what improvements must be introduced in existing methods of testing.

Recovery of Sulphur Dioxide from Waste Gases. H. F. Johnstone and A. D. Singh. (Industrial and Engineering Chemistry, 1937, vol. 29, March, pp. 286–297). The authors have investigated the design of scrubbers for large quantities of gases. Measurements of the rates of absorption and heat transfer and of the resistance to gas flow were made for a number of arrangements of (*a*) vertical smooth plates, (*b*) vertical corrugated plates, with horizontal corrugations, set at various spacings and with different depths and frequencies of corrugations, (*c*) grid surfaces with various channel dimensions and arrangements, and, for comparison, (*d*) ordinary tower packing such as Raschig rings, spiral rings and wire helices. The absorption data for sulphur dioxide by alkaline solutions and for ammonia by acid solutions were found to be accurately correlated with heat-transfer data by the Chilton-Colburn equation. Taking all factors into consideration, the most desirable packing of those studied for handling large quantities of flue gases is composed of grids with 1·5-in. channels and with individual sections from 4 to 6 in. high.

Hydrogenation Tests on Canadian Coal. T. E. Warren and R. E. Gilmore. (Industrial and Engineering Chemistry, 1937, vol. 29, Mar., pp. 353–358). The authors present the results of hydrogenation tests on a typical bituminous coal from Eastern Canada, and describe the equipment and method developed at the fuel research laboratories of the Canadian Department of Mines for such tests.

PRODUCTION OF IRON

Republic's New Furnace Goes Into Blast. (Blast Furnace and Steel Plant, 1937, vol. 25, Mar., pp. 300–301). Brief illustrated particulars are given of the new No. 4 blast-furnace in operation at the plant of the Republic Steel Corporation. The height of the furnace is 97 ft. 9½ in.; the dia. at the stock line 19 ft. 6 in.; the dia. at the bosh 28 ft. 3 in.; and the dia. at the hearth 25 ft. 6 in. The furnace is served by four stoves heated by pressure-type burners. Blast is provided by a turbo blower with a capacity of 75,000 cu. ft. of air at a pressure of 30 lb.

Rotary Machines for Blast-Furnace Operation. F. J. Taylor. (Iron and Steel Industry, 1937, vol. 10, Mar., pp. 306–310). A review of recent developments in the design and construction of turbo blowers for blast-furnaces.

Oxygen-Enriched Blast in Blast-Furnace Practice. C. Messerle. (Stal, 1936, No. 7, July, pp. 1–10). In connection with the first practical attempt to use oxygen-enriched blast in a large industrial blast-furnace, shortly to be started up at Makeevka, the author gives an account of previous experiments in this direction. He describes the influence of oxygen on the reactions in the furnace and the different possible methods of applying the oxygen-enriched blast. At Makeevka, generators making 20,000 cu. m. of oxygen per hr. at a cost less than 2 kops. per cu. m., will be installed. With blast containing 32% of oxygen the output of the blast-furnace will be doubled; slags of the Portland cement type and gas with a calorific value of 1110 cal. per cu. m. will be produced. The possibilities of a continuous delivery of metal by the blast-furnace and of the direct rolling of liquid metal are discussed. (In Russian).

Repairs to the Furnace Shaft under Blast. W. Owtcharenko. (Stal, 1936, No. 6, June, pp. 1–8). The author reports on the relining of the shafts of two blast-furnaces without stopping the blast. The operation took 5 to 6 days and the working of the furnaces was considerably improved afterwards. (In Russian).

A Study of Blast-Furnace Charging. G. Fox. (Iron and Steel Engineer, 1937, vol. 14, Mar., pp. 13–23). The author presents the results of a study of the mechanics of material handling which was made by Gipromez as a phase of the design of the 1000-ton standard blast-furnace adopted in most of the new Russian plants. The charging equipment determined upon for the initial blast-furnaces of this design includes bins arranged in a double row with two central coke bins. The coke bins are provided with coke screens and weighing hoppers for the automatic weighing and charging of coke. The other bins are provided with roller-type gates operated from the

scale car. The latter is of the two-compartment type. Skip tubs of large capacity are of the bail type and are operated at moderate speed by a single-drum hoist driven by a compound-wound motor supplied from the plant direct-current system. Bells are of the suspended type, not counterweighted. They are actuated by low-pressure pneumatic cylinders located in the skip engine-house under the skip incline. The valves controlling these cylinders are electrically operated. The small bell hopper is arranged for rotation. All charging operations are co-ordinated and interlocked by a fully automatic electric charging control system. A number of studies were made to determine the time required by the scale car for its movements and charging functions. Some of these studies are presented in chart form. Further studies and charts were made which depict the time requirements for coke weighing and charging, for skip, hopper and bell movements. These charts are of interest particularly in that they depict the relationships between the movements of the various elements of the charging system, they indicate what factors introduce limitations, and they demonstrate the importance of co-ordination of movements as a means of securing maximum results. The diagrams included in this discussion indicate that the charging equipment as described, with the charging methods proposed, has a potential capacity to burden the furnace for a production substantially in excess of its nominal rating. Dependent upon the charging round employed and the coke ratio per ton of iron, the charging operations incident to the production of 1000 tons of iron must be carried on from about 50% to about 85% of the total time. The limitations in charging capacity are found to lie principally in the scale-car movements. Only in a lesser degree is the capacity influenced by the skip-hoist movements and by the movements of the furnace-top mechanisms. The time requirements of the latter mechanisms are seen to be inimical to any substantial reduction in the time of movement of the skip hoist resulting from increase in its operating speed. A tabulation of results which might be obtained with a higher-speed skip hoist indicates that for the conditions in this case, a substantial increase in the speed of the skip hoist does not lead to a proportionate increase in charging capacity. It is further indicated that a substantial increase in speed of the skip hoist would involve a more than proportionate increase in the cost of electrically driven equipment, in addition to increased cost of other elements of the furnace construction. In view of the adequacy of charging capacity afforded by moderate-speed equipment, as indicated by the several studies made, it was decided that, for this design, the use of high speeds for any of the charging mechanisms was unnecessary and could not be justified. These mechanisms are large and involve heavy masses. Their operation is of a start-and-stop character. Inertia and kinetic energy are important considerations. Smoother, simpler operation, less impact stresses, lower power consumption and less maintenance

cost are inherent in the slower-moving mechanisms. The use of moderately speeded mechanisms, well co-ordinated, is preferable to that of high speeds which may be necessitated by poor co-ordination. The use of automatic coke weighing and fully automatic charging was decided upon in order to obtain the best possible co-ordination of equipment movements, to insure accuracy in maintaining charging schedules, to minimise delays, messes and annoyance caused by human errors, to charge definite coke weights, and to minimise costs. Bell suspension of the non-counterweighted type was selected in order to avoid heavy counterweights, particularly on top of the furnace, to minimise the likelihood of damage resulting from an explosion between the bells, and to permit of the use of a simple yet effective type of bell operation.

Utilisation of Slag in the Birmingham District, Alabama. J. R. Cudworth and J. C. Mead. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 796: Mining Technology, 1937, vol. 1, Mar., No. 2). The authors describe the raw materials from which the blast-furnace slag is formed, the chemical and physical characteristics of the slag and the preparation of the slag for various uses. The slag-crushing plants for concrete aggregates and for treating basic open-hearth slag are briefly discussed.

Sponge Iron Experiments at Mococo. C. C. Maier. (United States Bureau of Mines, 1936, Bulletin No. 396). A complete account is given of the experiments carried out at Mococo, near Martinez, California, on the production of sponge iron in a rotary furnace, using pyrite cinders as raw material.

The Equilibrium Diagram of the System $CaO.TiO_2.SiO_2$–$MnO.TiO_2$. K. Iwasé and U. Nisioka. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Nov., pp. 504–509). In order to find the composition of the slag of low melting point and high TiO_2 content in the iron sand refinery, the equilibrium of the system $CaO.TiO_2.SiO_2$–$MnO.TiO_2$ was studied; thermal and X-ray analysis as well as microscopic examination of the quenched specimens were employed. In this system $CaO.TiO_2.SiO_2$ takes up $MnO.TiO_2$ in solid solution; the solid solubility of the latter in the former is 18% by weight; a eutectic point lies at 49% of $MnO.TiO_2$ by weight (46·8% of TiO_2) and 1210° C.

New Orientations in Siderurgy. Lefebvre. (Association Technique de la Sidérurgie, Charleroi, Jan. 30, 1937: Génie Civil, 1937, vol. 110, Mar. 20, pp. 270–272). The author surveys modern tendencies in the metallurgy of iron and steel in England and Germany and then discusses the question of the introduction of these new methods into other steelmaking countries—Belgium, Luxemburg and France. With regard to England he indicates the recent evolution of the iron and steel industry and modern trends with regard to slag basicity, and touches briefly on operating results. Concerning Germany he reviews the economic problem, the German iron ores

and the question of manganese. In conclusion he considers the problem of the supply of ores, and the applicability of the new processes in France, Belgium and Luxemburg.

Metallurgical Progress in the Australian Commonwealth. J. N. Greenwood. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1936, No. 103, Sept. 30, pp. 209–235). In this review of progress in the metallurgical industries of Australia, the author makes brief reference to the iron and steel industry established at Newcastle and Port Kembla in New South Wales.

The Future of Siderurgy in Tonkin. (Génie Civil, 1937, vol. 110, Feb. 13, p. 165). While mineral deposits in Tonkin on which an iron industry might be based have been known for some time, yet the iron ores are of low grade, and the local demand is low, so that the prospects of success were not bright. Japan nowadays, however, is importing both ore and iron, and richer iron ore deposits containing up to 70% of iron have been discovered in close proximity to transport means; as suitable coking coals and supplies of limestone are also available, it would appear that the production on site of pig iron for export to Japan might be economically feasible.

FOUNDRY PRACTICE

Mechanical Aids for Increasing Foundry Production. J. Tinbrell. (Institute of British Foundrymen : Foundry Trade Journal, 1937, vol. 36, Apr. 8, pp. 287–290, 292). The author describes various mechanical equipment for the preparation and handling of sand, mould carrying and casting.

Behaviour of Manganese in the Cupola. M. T. Davis. (Transactions of the American Foundrymen's Association, 1936, vol. 44, pp. 592–605). The author has conducted a series of tests to determine the loss of manganese in a 36-in.-dia. cupola. The objects of the experiments were to study quantitatively cupola manganese losses, and to establish a relationship between the losses and the position of the charges in the cupola. Three series of tests were run in which the method of charging was varied. The results show that in a long series of charges of high-test cast iron, there is a gradual increase in the loss of manganese. In the cupola used in the experiments, the loss was 25% at the beginning, and 40% near the end. High temperatures are partly responsible for high losses of manganese, and therefore long heats of high-test cast iron ultimately attain higher losses than shorter heats. With regard to compensating manganese additions in the cupola, the author points out that extra manganese in the form of manganese briquettes did not raise the ultimate manganese content sufficient to justify this method. The greater the manganese additions to the cupola the greater were the losses, running as high as 45% loss for a calculated analysis of 1·15% manganese. Therefore no attempt was made to compensate for this loss as too much manganese would be lost by oxidation. Attempts to compensate for this loss were more successful in the ladle if too much of the alloy was not added.

Amorphous Graphite Lowers Chill and Hardness. (Foundry, 1937, vol. 65, Feb., pp. 35, 90). It is stated that the addition of amorphous graphite to molten grey cast iron reduces chill, decreases the hardness and improves the machinability of the metal. The greatest benefit of the graphite addition is obtained when it is added to the metal coming from the spout. The metal temperature should be between 2650° and 2750° F. to obtain best results, and a time of at least 2 min. should be allowed to ensure adequate reaction between the metal and graphite. If an electric furnace is employed, the graphite may be added to the bath, as soon as it becomes molten. The usual additions of the graphite range from two to four pounds per ton of metal.

Malleable Castings Clean Annealed in New Type Furnace. (Heat Treating and Forging, 1937, vol. 23, Feb., pp. 95–97). Brief par-

ticulars are given of a new type of continuous furnace for the short-cycle annealing of malleable castings in a controlled atmosphere.

A.F.A. Grain Distribution Numbers for Foundry Sand. (Transactions of the American Foundrymen's Association, 1936, vol. 44, pp. 545–551). Particulars are given of the method for determining the A.F.A. grain distribution number for foundry sands, which has been prepared by the Sub-Committee on Grading of the Foundry Sand Research Committee of the American Foundrymen's Association.

Upon Properties of Moulding Sands of Nippon and Manchoukuo. K. Matuzuka. (Memoirs of the Ryojun College of Engineering, 1936, vol. 9, No. 10, Dec., pp. 223–303). The author presents a detailed account of his investigation of moulding sands from Nippon and Manchoukuo. Part I. is concerned with the mechanical analysis of the sands; the apparatus used is described and the results obtained are discussed. Part II. deals with the physical properties of moulds made of the sands; details of the ramming apparatus, permeability test and strength test, and of tests on tempering, ramming, permeability and strength are given; and the optimum water content, the relation of the water content to the degree of ramming, variations in the permeability and strength and the types of casting for which the sands can be used (some are suitable for iron) are discussed. In Part III. the author describes his experiments on the bonding materials of these sands; tests on dehydration, on expansion and contraction, and thermal analyses were made, and the results are set out and discussed. Part IV. relates to the determination of the properties of the sands by casting experiments; the durability of the sands and its effect on the bonding material, and the burning-on of the sands (reference being made to the case of steel castings) are dealt with. Finally, in Part V. the author discusses the mineralogical composition and geological origin of the sands, the requisites in good moulding sands, and desiderata in prospecting for moulding sands.

Runners and Risers for Cast Iron. R. F. Coates. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Mar. 25, pp. 257–258). A brief discussion of the design and positioning of runners and risers for iron castings, with special consideration to the speed of filling the mould and the direction of flow of metal.

Packard Remodels its Foundry. P. Dwyer. (Foundry, 1937, vol. 65, Feb., pp. 22–24, 82). Illustrated particulars are given of the remodelled foundry at the plant of the Packard Motor Co., Detroit, the capacity of which has been increased approximately 50%. The iron is melted in four 84-in.-dia. cupolas.

Foundry Specialises in Difficult Jobs. P. Dwyer. (Foundry, 1937, vol. 65, Mar., pp. 22–24, 89–90). Illustrated particulars are given of the plant and practice at the grey iron foundry of the Frank Foundries Corporation, Davenport, Iowa.

PRODUCTION OF STEEL

Appleby-Frodingham Steel Co., Ltd. (Iron and Steel Industry, 1937, vol. 10, Mar., pp. 291–296; Apr., pp. 331–334). The plant of the Appleby-Frodingham Steel Co., Ltd., is described and illustrated. (*See* Journ. I. and S.I., 1937, No. I., p. 260 A).

Extensions and Reconstruction at the Burbach Works. A. Wagener. (Revue Technique Luxembourgeoise, 1937, vol. 29, Mar.–Apr., pp. 21–33). (*See* Journ. I. and S.I., 1937, No. I., p. 158 A).

Observations on Swedish Bessemer Process. I. Forslund and A. Wahlberg. (Jernkontorets Annaler, 1936, vol. 120, pp. 659–684). During several heats with varying silicon contents in the charge the gradual changes in temperature, blast consumption, steel and slag analysis were determined. There is an optimum silicon content that gives more rapid refining and rise of temperature than higher or lower values. When the silicon is too high the air bubbles are probably lined with a film of silica that more or less prevents further reaction between the oxygen of the bubble and the steel. After the silicon has been sufficiently removed by oxidation, the oxide film will contain MnO also and the reaction will then be accelerated. Based on the manganese content of the steel and the temperature, a comparison is made between the finishing analysis for steel and slag and equilibrium values according to Körber and Oelsen. Good agreement is found for silicon, ferrous oxide, manganese oxide and silica, but actually the carbon values are high owing to sluggish carbon reaction.

Random Thoughts of an Idle Steel Man. F. H. Crockard. (Iron Age, 1936, vol. 138, Dec. 17, pp. 32–37, 45; Dec. 24, pp. 19–23, 60; Dec. 31, pp. 26–29, 39). A series of articles in which the author sketches the technological growth of steel manufacture in America and outlines a number of practices which could contribute to lower production costs and simplify operations in the future.

Working of Large Open-Hearth Furnaces. L. Granberg. (Stal, 1936, No. 7, July, pp. 27–36). A detailed description is given of the open-hearth department of the Dzershinski Works, erected in 1933. It contains three furnaces with a total bath surface of 152 sq. m. The ingots produced weigh 5 to 7 tons, and 30,000 to 33,000 tons of steel are made per month. (In Russian).

Experiments on the Production of Manganese Sheet Steel. P. Kravtzov, J. Shneerov, S. Fetisov and A. Lopatin. (Stal, 1936, No. 6, June, pp. 26–38). The authors deal with the occurrence of blow-holes in manganese sheet steel for shipbuilding. These blow-holes, which caused for some time the rejection of up to 40% of the production of the Ilijtch works, are filled with pure hydrogen.

They are formed in contact with slag inclusions. The larger number of such inclusions in manganese steel as compared with ordinary steel is due to the strong action of manganese on refractory materials, especially on the lining of the ladle. The shorter the time during which the metal remains in the ladle, the smaller is the number of blow-holes. By improving the methods of casting, the proportion of rejected sheets was reduced to 7%. (In Russian).

Production of Disc Steel. A. Dudar. (Stal, 1936, No. 6, June, pp. 9–22). The author describes experience gained in the Enakievo Metal Works in producing disc steel. He gives statistical tables regarding the relation of hardness to composition based on 8000 tests, showing that variations of hardness from 230 to 300 occur even if the sum of the carbon content plus one-third of the manganese content is constant. He further describes nine trial heats in which all stages of the process were carefully controlled and gives a number of indications as to the most efficient methods. (In Russian).

New Capacities of the Open-Hearth Department of the Komintern Works. T. Voronov, M. Lockshin, G. Iserson and S. Broit. (Stal, 1936, No. 7, July, pp. 11–26). A detailed description is given of the open-hearth department of the Komintern Works, consisting of two furnaces (bath area, 35 and 38 sq. m.); the average daily production in April 1936 was 523 tons of steel. (In Russian).

Mechanism of Reduction of Silicate Inclusions in Steel by Added Aluminium. A. Portevin and R. Castro. (Jernkontorets Annaler, 1936, vol. 120, pp. 738–740). The mechanism described by K. Amberg and A. Hultgren (Jernkontorets Annaler, 1936, pp. 311–342; *see* Journ. I. and S.I., 1937, No. I., p. 162 A) is considered not to be the only one possible. Dissolved aluminium may reduce the silicate drops without immediate formation of a crystalline phase. This would not form until, on cooling, the solubility for the silico-aluminate in the melt rich in alumina and silica is exceeded. In this way the spherical shape of the inclusions will be preserved. In support hereof, the following experiment is described. From a low carbon steel to which silicon had been added two 1-kg. test ingots were cast, No. I. without further addition, No. II. with the addition of 0·2% of aluminium. In No. I. spherical glassy inclusions were found, according to residue analysis consisting largely of SiO_2. In No. II. the inclusions were similar but somewhat less transparent, in dark-field illumination deep green. Residue analysis (chlorine method) gave: $O_{SiO_2} = 0{\cdot}0155$, $O_{Al_2O_3} = 0{\cdot}038\%$, O_{FeO} and O_{MnO} nil. Near their circumference the inclusions contained small metallic droplets probably rich in silicon and formed by reduction of SiO_2. No crystals were observed in the inclusions. In their reply (Jernkontorets Annaler, 1936, vol. 120, pp. 740–744), Amberg and Hultgren assume that the Al_2O_3 content in the residue from No. II. may have been largely due to the presence in the matrix of small Al_2O_3 or aluminium silicate crystals precipitated by reaction with dissolved oxygen in the metal, whereas the reaction between aluminium and

the silicate inclusions in the short time available would probably not exceed the limit of solubility of Al_2O_3 in the SiO_2 melt, which should be at a moderate amount of Al_2O_3. Their views on the various reaction products from the addition of aluminium to steel are further elaborated.

Stainless Steel Produced in Hollow Electrode Furnace. D. M. Scott and A. W. F. Green. (Foundry, 1937, vol. 65, Feb., pp. 28–30, 88). Particulars are given of the use of hollow electrode furnaces for the production of stainless steel at the plant of the Ludlum Steel Co. (*See* Journ. I. and S.I., 1937, No. I., p. 213 A).

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," was the following:

C. H. Desch: The solidification of ingots.

On the Formation of Flakes in Steel Ingots. K. Honda and T. Hironé. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Dec., pp. 713–725). The internal pressure in minute cavities present in steel ingots caused by the evolution of dissolved hydrogen gas during cooling was calculated, and it was found that, as the temperature decreases the pressure increases, attaining a maximum at about 300–200° C., then diminishes linearly and vanishes at the temperature of absolute zero. It is concluded that the effect of this pressure, combined with thermal and transformation stresses, is the real cause of the formation of flakes in steel ingots; many observed facts regarding the formation of flakes are discussed from this point of view, and comments are made on Schenck's hydrogen theory of the formation of flakes. The authors' views on the prevention of flake formation in steel ingots are given.

FORGING, STAMPING AND DRAWING

Design of Drop Forging Dies. G. A. Smart. (Heat Treating and Forging, 1937, vol. 23, Jan., pp. 17–19, 24; Feb., pp. 67–70). A series of articles in which the author discusses a number of problems in the design of drop-forging dies.

Alloy Cast-Iron Dies. A. B. Everest. (Sheet Metal Industries, 1937, vol. 11, Feb., pp. 186–187). The author discusses the application of alloy cast-iron dies for the press working of sheet metal in the automobile industry.

Buick Takes Another Forward Step in Forge Practice. R. H. Darnton. (Iron Age, 1937, vol. 139, Mar. 25, pp. 28–29, 50). Equipment and practice at the plant of the Buick Motor Co. for the forging of automobile crankshafts are described and illustrated.

Some Aspects of Press Forging. J. H. Hurst. (Metal Treatment, 1937, vol. 3, No. 1, Spring issue, pp. 3–7). After referring to the difference between rolls, hammers and presses with respect to their action on the metal, the author goes on to deal with some of the most important features of press forging. Attention is first directed to what happens during a squeeze, and in this connection penetration and the general movement of metal are considered. Following this, forging pressures, reduction, grain flow, and centre and corner segregation are dealt with and some comments are made on heating.

Forging Machines and Hot Presses. P. Verborg. (Metal Treatment, 1937, vol. 3, No. 1, Spring issue, pp. 46–47). An abridged English translation of an article, which appeared in Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Feb. 20, pp. 231–235, describing recent developments in the design of forging machines and hot presses, as illustrated by the exhibits at the Leipzig Fair. (*See* Journ. I. and S.I., 1937, No. I., p. 266 A).

Presses and Sheet Metal Machinery. O. P. Hatton. (Iron Age, 1937, vol. 139, Jan. 7, pp. 381–389; Jan. 14, pp. 46–51, 104, 106). A review of recent improvements in the design of hydraulic and mechanical presses.

Modern Wire-Drawing Machines. E. Schröder. (Engineering Progress, 1937, vol. 18, Feb., pp. 32–36). Illustrated particulars are given of various types of wire-drawing machines of German design.

ROLLING-MILL PRACTICE

The Nomy Pad Bearing [*Blocklager*], a Novel Type of Frictional Bearing. T. Dahl. (Stahl und Eisen, 1937, vol. 57, Mar. 25, pp. 313–318). The feature of the Nomy bearing is that the rotating bearing surface is divided into a number of small parts or "pads," which are supported away from their middle points. In operation these pads automatically take up a position forming a small angle with the outer fixed bearing surface. The resulting wedge-shaped oil layer enables the pads to support very heavy loads, while the frictional resistance and the wear are low, owing to the fluid character of the friction. The pads have a supporting edge for both directions of rotation, and automatically rest against the appropriate stops; thus the bearing functions regardless of the direction of rotation. The Nomy bearing can be used in rolling-mills.

Lubrication in the Cold Working of Metals. (Metal Industry, 1937, vol. 50, Mar. 26, pp. 383–385). An account is given of a discussion which took place at a meeting of the Midland Metallurgical Societies on problems of lubrication in the cold-working of metals.

Increase in Efficiency of the Blooming Mill by the Use of Hot Ingots. G. Hillmann and L. Shwartzmann. (Stal, 1936, No. 6, June, pp. 39–44). The authors report on the increase in output of the Stalino Metallurgical Works blooming mill which has been achieved by an acceleration of the transport of ingots from the heating furnaces to the mill. The ingots are now delivered to the blooming mill soaking pits with a mean temperature of 900° C. The time required for heating them and the cost of fuel are correspondingly lowered. (In Russian).

Most Favourable Temperature for Rolling Bessemer Steel Rails. A. Baby. (Stal, 1936, No. 7, July, pp. 77–89). The author investigated the influence of the temperature of rolling on the mechanical properties of rails. He found that for "soft" rails (in which the sum of the carbon content plus one-quarter of the manganese content = 0·53–0·60%) the initial temperature of rolling must be higher than 1060° C. and the final temperature below 915° C. For "medium" rails (in which the sum of the carbon content plus one-quarter of the manganese content = 0·61–0·66%) the corresponding temperatures are 1070° C. and 935° C., and for the "hard" rails (in which the sum of the carbon content plus one-quarter of the manganese content = 0·67%) 1090° C. and 960° C., respectively. (In Russian).

The Plate and Sheet Department of S.A.F.E. (Sheet Metal Industries, 1937, vol. 11, Feb., pp. 145–150). The layout and equipment of the hot sheet mill and cold-rolling mill in operation at the

Hagondange plant of the Société des Aciers Fins de l'Est are described and illustrated.

A 100 in. Semi-Continuous Sheared Plate Mill. (Iron and Steel Industry, 1937, vol. 10, Mar., pp. 297–303). An illustrated description is given of the new plate mill in operation at the Homestead plant of the Carnegie-Illinois Steel Co. (*See* Journ. I. and S.I., 1937, No. I., p. 267 A).

Cold Rolling Deep-Drawing Steels. J. L. Turner. (Metallurgia, 1936, vol. 15, Dec., pp. 39–41; 1937, Jan., pp. 73–75; Feb., pp. 109–111). The author discusses the hot-rolling, cold-rolling and heat treatment of steel for deep-drawing. The mechanism of deformation during rolling, the refinement of structure and the effect of straining and heat treatment on the steel are dealt with.

The Mechanics of Cold Rolling. W. Trinks. (Blast Furnace and Steel Plant, 1937, vol. 25, Mar., pp. 285–288). The author discusses the cumulative effect of pressure upon the friction hill, the flattening of the rolls by pressure and the effect of front and back tension on roll flattening and roll pressure.

Cold Drawing Seamless Steel Tubes. H. C. Knerr. (Transactions of the American Society for Metals, 1937, vol. 25, Mar., pp. 114–128). The author gives a brief outline of the elementary principles involved in the art of producing cold-drawn seamless steel tubing, touching upon methods, equipment, and tools. Representative examples of the flow of metal, grain size and physical properties resulting from cold-drawing are given.

Roller Straightening Machines. L. Reichert. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Mar. 27, pp. 385–387). The author reviews recent developments in roller straightening machines. Attention has been paid to the ease of changing the rolls, increased power economy by the use of roller bearings, and improved quality of the goods by the incorporation of supplementary straightening rolls.

HEAT TREATMENT

Metallic Cementation. X. Cementation of Tungsten on Some Metals. T. Kase. (Kinzoku no Kenkyu, 1937, vol. 14, Jan. 20, pp. 22–33). The author has studied the cementation of iron, nickel and copper by tungsten at various temperatures between 800° and 1350° C. (In Japanese).

Metallic Cementation. XI. Cementation of Molybdenum on Some Metals. T. Kase. (Kinzoku no Kenkyu, 1937, vol. 14, Feb. 20, pp. 75–86). Using pulverised ferro-molybdenum the author has studied the cementation of iron and nickel by molybdenum at temperatures between 800° and 1300° C. (In Japanese).

Surface Hardening by Local Heat Treatment. (Metal Treatment 1937, vol. 3, No. 1, Spring issue, pp. 43–45, 47). Various applications of the Shorter hardening process are dealt with.

Controlling a Controlled Atmosphere. A. E. Krogh. (Metals and Alloys, 1937, vol. 8, Feb., pp. 47–51 ; Mar., pp. 83–88). The author discusses briefly the effect of furnace gases upon steel during heat treatment and describes an investigation carried out to determine those characteristics of furnace atmospheres which can best be used as a means of measuring the conditions existing in a furnace, and to develop a meter to record graphically the " quality " of furnace atmospheres.

Electric Heat-Treating Developments in England. A. G. Robiette. (Heat Treating and Forging, 1937, vol. 23, Feb., pp. 92–94, 96–97). Recent progress in the design and application of electric heat-treatment furnaces in England are discussed.

The Heat Treatment of Cast Iron. J. E. Hurst. (Iron and Steel Industry, 1937, vol. 10, Feb., pp. 285–288; Mar., pp. 325–327). The author discusses nitrogen hardening, surface hardening and special heat treatments for cast iron.

Heat Treatment of Wear-Resisting Grey Cast Iron. R. Hanel. (Giesserei, 1937, vol. 24, Mar. 26, pp. 149–153). The author first discusses the influence of the structure (quantity and distribution of the graphite, the character of the matrix) of cast iron on its resistance to wear, and then deals with the production of a martensitic structure, including the theory and practice of its production, the depression of the transformation by quenching alone, partly by quenching and partly by alloying, and by alloy alone, and the heat treatment of austenitic cast iron.

High-Speed Steels. E. Pasley. (Wild Barfield Heat-Treatment Journal, 1937, vol. 2, Mar., pp. 51–54). The author discusses the characteristics of high-speed steels with special reference to their heat treatment.

The Hot Working and Heat Treatment of Carbon Tool Steels. R. A. Malmberg. (Industrial Heating, 1937, vol. 4, Jan., pp. 22–24; Feb., pp. 101–104, 116; Mar., pp. 193–196). A series of articles in which the author discusses the correct procedure for the hot-working and heat treatment of carbon tool steels, including methods of heating, forging, annealing, hardening and tempering.

The Heat Treatment of Wire Strip and their Manufactures. (Wire Industry, 1936, vol. 3, Nov., pp. 463–469; Dec., pp. 517–521; 1937, vol. 4, Jan., pp. 19–24; Feb., pp. 61–69; Mar., pp. 121–123). A series of articles describing modern processes in the heat treatment of wire and wire products. Particulars are included of furnace construction and operation.

Improvement in Quality of Rails by Sorbitisation (Experience of the Kertch Works). V. Datta and P. Ivanov. (Stal, 1936, No. 6, June, pp. 67–77). The thermal treatment of rails (sorbitisation) makes it possible to obtain a tensile strength greater than 90 kg. per sq. mm. for the upper part of the rail (8·10 mm. thick) without affecting the toughness of the rail as a whole. It is preferable to increase the tensile strength by sorbitisation rather than by increasing the carbon content, because the first-mentioned method does not reduce the limit of proportionality. (In Russian).

Heat Treating in Ball Bearing Manufacture. C. T. Hewitt. (Heat Treating and Forging, 1937, vol. 23, Feb., pp. 63–66). The author describes the equipment of the heat-treating department of the Fafnir Bearing Co., New Britain, Connecticut, for the heat treatment of component parts for ball bearings.

Evolution of Gas During the Annealing of Steel Sheets. H. Monden and K. Skroch. (Sheet Metal Industries, 1937, vol. 11, Feb., pp. 267–270). An English translation of the authors' paper which appeared in Stahl und Eisen, 1936, vol. 56, Dec. 17, pp. 1532–1535. (*See* Journ. I. and S.I., 1937, No. I., p. 169 A).

The Tension Electric Heat-Treatment Process for Long Steel Members. H. N. Wylie. (Wild Barfield Heat-Treatment Journal, 1937, vol. 2, Mar., pp. 46–50). Particulars are given of the Tension electric process, in use at the plant of Sir W. G. Armstrong Whitworth Aircraft, Ltd., for the heat treatment of long steel members. The member is held at the ends by metal grips, and is thus suspended, usually in free air. It is heated by the passage through it of an electric current which brings it very rapidly to a uniform temperature, which is maintained for a few seconds; the current is then switched off and the member is cooled sufficiently rapidly to ensure adequate hardening. Tempering is effected by a smaller current maintained for a longer time. The advantages of the process are pointed out.

WELDING AND CUTTING

Oxy-Acetylene Welding of Sheet Metals. C. G. Bainbridge. (Sheet Metal Industries, 1937, vol. 11, Feb., pp. 217–220). The author emphasises those factors to be observed in the production of strong sound welds by the oxy-acetylene process. He discusses welding technique and draws attention to the benefits to be derived from the use of jigs in the joining of sheet metals.

What Happens during Welding and Cutting. G. V. Slottman. (Welding Journal, 1937, vol. 16, Feb., pp. 9–13). The author discusses the nature of the oxy-acetylene flame, the practical application of the oxy-acetylene flame and the fundamentals of oxy-acetylene cutting.

Welding Procedure. A. R. Moon. (Institute of Welding: Welding Industry, 1937, vol. 5, Mar., pp. 68–78). The author discusses in a general way various aspects of welding and their relation to welding procedure.

Recent Improvements in Automatic and Semi-Automatic Machines for Arc Welding. R. Sarazin. (Welding Industry, 1937, vol. 5, Mar., pp. 53–58). A review of developments in the design and operation of automatic and semi-automatic arc welding machines, with special reference to French practice.

Fluxes—Their Function in Metallic Arc Welding. D. L. Mathias. (Welding Journal, 1937, vol. 16, Feb., pp. 20–24). The function of a light flux coating is to stabilise the arc through the formation of a highly ionised vapour or gas surrounding the arc, and to control the melting rate of the electrode and the penetration of the base metal by altering the distribution of thermal energy in the arc. In addition to improved arc stability and control of deposition rate and penetration obtained through the use of light flux coatings, the heavy flux coating of the covered electrode serves to prevent atmospheric contamination of the deposited metal by the formation of a vapour or gaseous envelope around the arc. It supplies weld metal of the desired composition either by maintaining the original composition of the core wire or through the introduction of added elements. Its function is also to retain the metal in a fluid condition, by means of a slag blanket, long enough to allow for the evolution of contained gases, and the separation of non-metallic impurities. It also utilises the heat liberated in the arc to anneal or refine the metal in the layers preceding the last layer deposited.

Welding Cast Iron. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Mar., Supplement, pp. 2–32). The authors present a review of the literature on cast iron welding, which is intended to provide welding engineers with a convenient summary

of the methods adopted and materials used in the welding, bronze welding and fusion cutting of cast iron, and of the metallurgical principles involved, as well as of the physical properties obtained. The majority of the references quoted are from the literature published during the past ten years.

Metallurgical Problems of Welding in the Automobile Industry. A. Di Guilio. (Welding Journal, 1937, vol. 16, Mar., pp. 9–14). The author reviews the various welding processes used in automobile construction and discusses some of the metallurgical problems involved.

Physical Properties of Welds. G. E. Claussen. (Welding Journal, 1937, vol. 16, Mar., pp. 16–19). The physical properties of bare- and covered-electrode welds in mild steel are compared. The low carbon content and high inclusion and nitrogen contents of bare electrode weld metal account for its inferior properties in all respects. A table is given which shows the properties that may be expected in low alloy steel welds as compared with the base metal of the same composition.

Some Tensile Tests of Weld Metal at Varying Temperatures. T. R. B. Sanders. (Welder, 1937, vol. 9, Feb., pp. 38–41). The author describes a preliminary investigation into the effects of increased temperature on the behaviour of weld metal under the tensile test.

Influence of Shrinkage Compressive Stresses in Welded Compression Members on the Notch Strength. G. Grüning. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Mar. 27, pp. 393–394). The results of tests are reported showing the influence of shrinkage compressive stresses on the notch strength of welded compression members, the weld being at right angles to the direction of the working stress.

British Standard Specification for Fusion Welded Steel Air Receivers (not intended for Transport). (British Standards Institution, No. 487–1937). This specification covers any vessel intended to contain air or inert gas above atmospheric pressure. The material used in the construction of a receiver shall be either acid or basic open-hearth mild steel. The cast from which the plates are rolled shall not contain more than 0·05% of sulphur or of phosphorus.

CLEANING AND PICKLING OF METALS

Keep Down the Cost of Snagging and Billet Grinding. R. M. Johnson. (Iron Age, 1937, vol. 139, Apr. 15, pp. 49–51). The author discusses the factors to be considered in the selection of the right type of grinding wheel and machine for the snagging and grinding of different steels. The machines and abrasives recommended for different materials are tabulated.

A Chemical Study of Alkaline Cyanide Degreasing and Coppering Baths. A Chaybany. (First International Electrodeposition Conference, London, Mar. 3–4, 1937).

Electrolytic Pickling of Iron and Steel. R. Müller. (Berg- und Hüttenmännisches Jahrbuch, 1936, vol. 84, Oct. 27, pp. 108–115). It is shown that the most suitable electrolyte for electrolytic pickling is $\frac{1}{2}$ to 1 *N* relative to ferrous salt and contains 0·5 to 0·8% of acid. In cases where a very short pickling time is desired, the use of a concentrated ferrous chloride solution, to which hydrochloric acid has been added, is indicated, as is also an increase of temperature. The author points out, however, that the raising of the temperature beyond 30° and up to 40° involves a deterioration in the quality of the pickled surface, as pitting may take place. This effect is apparently caused by the joint action of the activating influence of the ferrous chloride solution and the increased temperature, which induces an increasingly irregular attack on the surface. An increase of the current density beyond 10 amp. is not followed by any considerable acceleration of the pickling process. For economic reasons it is advisable to work with much smaller current densities (0·5 to 1 amp.).

Cleaning and Pickling Tanks Heated by Simple Economical Gas Method. J. B. Nealey. (Steel, 1937, vol. 100, Feb. 22, pp. 60–62, 73). Particulars are given of a method of heating cleaning and pickling tanks by the use of immersed gas burners.

Inhibited Pickling Solutions in General Finishing Shop Practice. P. Mabb. (Metallurgia, 1937, vol. 15, Mar., pp. 141–145). A number of commercial inhibitors for hydrochloric acid and sulphuric acid pickling solutions are considered and compared on a practical basis. The author demonstrates a method for determining the optimum concentration of inhibitor, its efficiency over a range of concentrations, its protective action on the metal pickled, and the consequent saving in acid consumed.

COATING OF METALS

British Electroplating Practice. E. J. Dobbs. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). A review of British practice in the electrodeposition of nickel, chromium, copper, cadmium, tin, zinc and rhodium is presented.

German Electroplating Practice. R. Springer. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). The author summarises German practice in the electroplating of various metals, such as nickel, chromium, tin, cadmium, aluminium, &c. He refers to the anodic oxidation of aluminium as a means of protecting it against corrosion and mechanical wear, and for decorative purposes; the anodic film can be dyed. The Bullard-Dunn process for electrically descaling hardened steel is now used by about twenty large firms in the motor-car, aero engine and metal industries; the method is not described, however.

French Nickel Plating Practice. M. Ballay. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). Developments during the last ten years and the present position of nickel plating in France are reviewed.

Studies in Evaluating the Brightness of Electrodeposits. B. Egeberg and N. E. Promisel. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). When the eye evaluates the brightness of an electrodeposit, various psycho-physical factors are in play. The combined effect of these factors has been evaluated in a graphical way and by mathematical expression, which serve as references and methods of comparison without the need for the actual samples to be at hand for visual observation.

Inclusions in Electrodeposits, their Origin and their Effect on the Structure and Mechanical Properties. M. Cymboliste. (First International Electrodeposition Congress, London, Mar. 3–4, 1937). The author describes the types of inclusions that may occur in electrodeposited metals and discusses their origin and their influence on the structure and mechanical properties of the deposits. The paper is accompanied by numerous micrographs.

Blister Pits in Electrodeposits. M. Cymboliste and J. Salauze. (Electrochemical Society, May 1937, Preprint No. 71–16). Under certain plating conditions, characteristic minute blisters or blister pits will form in nickel, copper and other deposits. Apparently, these blister pits are due to small gas bubbles which adhere to the plate and are gradually closed in and covered up with metal; or, the blister pits may be due to colloidal or suspended matter of some kind or other which attaches itself to the plate and then, especially when the electrical conductivity of these particles is

relatively high, metal will electrodeposit on top of these particles. Microphotographs illustrate the different cases of blister pits encountered. These photographs indicate that as a rule the blister pits are fundamentally due to flocculent basic salt particles which attach themselves to the surface of gas bubbles.

Measuring the Plating of Screw Threads. E. C. Erickson. (Wire and Wire Products, 1937, vol. 12, Mar., pp. 144–145). Particulars are given of an optical contour projector for determining the thickness of coatings on screw threads.

A Method of Obtaining Adherent Electrodeposits on Chromium and Stainless Steel. G. E. Gardam. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). The method described for producing adherent deposits on electrodeposited chromium and high-chromium alloys consists in cathodic polarisation for 5 min. at 150 amp. per sq. ft. and 35° C. in a solution containing 240 g. of nickel sulphate and 50 g. of sulphuric acid per litre, followed by nickel deposition and heat treatment, or, preferably, by copper deposition. Chromium alloys (*e.g.*, stainless steels) can be soft-soldered with ordinary fluxes after treatment for 5 min. in the acid nickel sulphate solution. The method has been used to study the adhesion of chromium deposits to various metals.

The Hardness of Electrolytic Chromium. M. Cymboliste. (Académie des Sciences, Mar. 15, 1937 : Génie Civil, 1937, vol. 110, May 1, pp. 400–401). The author has determined the influence of the conditions in the electrolytic bath on the hardness of electrodeposited chromium ; chromic acid baths were used. The presence of foreign anions in the liquid decreases the hardness, while cations increase it. For a constant ratio of chromic ions to sulphate radicle, increasing the chromium content reduces the hardness. Below 55° C., an increase in the current density diminishes the hardness of the deposit, but above that temperature its effect is reversed. As the bath temperature rises, the hardness increases to a maximum at about 50° C., and then decreases again. By varying the conditions suitably the author was able to make the hardness vary between 1200 and 400 Brinell. The hardness was measured on deposits at least 0·5 mm. thick by means of diamond indentors.

Drum-Ring Bath for Electroplating. E. Springer. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Apr. 10, p. 440). The plating plant described is particularly suitable for dealing with small objects. The electrolyte is contained in an annular bath. The objects to be plated are loaded into suitable drums, and these are suspended by their axles on open bearings fitted to the rotating rim of the bath. The rim and the drums rotate independently, the rate of travel of the rim being adjusted to the required period of plating. At the unloading point each drum is removed by an overhead conveyor and carried to the rinsing and drying appliances. The rotating rim carries six drums at a time.

Bright Nickel Plating. L. W. Johnson. (Electrodepositors' Technical Society: Metal Industry, 1937, vol. 50, Feb. 26, pp. 281–286). The author presents a summary of existing technical and patent literature dealing with the subject of bright nickel plating.

A Study of Electrodeposits Containing Nickel and Sulphur. W. T. Young and H. Kersten. (Electrochemical Society, May 1937, Preprint, No. 71–4). Electrodeposits containing nickel and sulphur were formed from an electrolyte containing essentially nickel ammonium sulphate and sodium thiosulphate. The composition of the deposits was found to depend on the current density, and ranged from about 27% of sulphur and 72% of nickel, to 8% of sulphur and 87% of nickel. Four different structures were observed: Nearly pure Ni_3S_2; the same plus an unknown structure; an amorphous structure; and a poorly crystallised nickel structure.

Cadmium as an Auxiliary Plating. E. E. Halls. (Metal Treatment, 1937, vol. 3, No. 1, Spring issue, pp. 27–33). The author considers a number of electrodeposited finishes, namely, zinc, copper-nickel, cadmium-nickel, copper-nickel-chromium and cadmium-nickel-chromium, with particular attention to the value of cadmium as a first coat. The relative resistance to corrosion of finishes of different composition and thickness is illustrated by results obtained in outside exposure, salt spray and varying humidity tests.

The Cyanide Cadmium Plating Solution. G. Soderberg. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). A review of data and other information regarding the standard cadmium-plating solutions now in use.

Electrodeposition of Manganese Using Insoluble Anodes. C. G. Fink and M. Kolodney. (Electrochemical Society, May 1937, Preprint, No. 71–3). The authors have investigated the electrodeposition of manganese using both chloride and sulphate baths.

Recent Experiences on the Properties and Workability of Clad Sheets. W. Rädeker. (Zeitschrift für Metallkunde, 1937, vol. 29, Jan., pp. 1–8). One metal may be clad with another by three processes: (1) By cold-rolling them together; adhesion is obtained solely by anchorage in surface roughnesses. (2) By hot-rolling; here adhesion is provided by anchorage in the grain boundaries and also by the formation of a bond by diffusion. (3) By melting an intermediate layer, as in soldering or brazing. The author describes tests made on the adhesion of the clad metal by bending and twisting; the best adhesion was obtained when the clad metal was anchored in the grain boundaries of the basis metal and a diffusion layer without brittle components was formed. If the process is correctly carried out the bond does not break down in fatigue tests or under temperature variations. The strength properties, the specific gravity, the thermal conductivity and the specific heat of the clad sheet can be derived from those of the two metals and their relative proportions. When iron is plated with nickel, copper or

austenitic steel, the diffusion layer produced is very thin; the quantities diffusing are so small that they are absorbed in solid solution. With proper technique satisfactory welds can be made in clad sheets.

Phosphate Rust Protection. O. Haehnel. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Apr. 24, p. 488). A brief review of methods of protection against rusting by means of phosphate coatings, and the application, defects, and properties of the coatings is given.

The Tinning of Steel Strip by Electrodeposition. Part I. Electrodeposition and Polishing of Thin Coatings of Tin on Steel. D. J. Macnaughtan, W. H. Tait and S. Baier. (Electrodepositors' Technical Society and the Iron and Steel Institute, Jan. 13, 1937). Experimental work has been carried out on the tin-plating of steel strip to enable some of the technical factors involved in the process to be studied. In particular, it was desired to obtain material for comparative tests of the quality of different tin coatings produced under known conditions. Continuous plating of strip 2 in. wide was carried out in: (1) Alkaline stannate solution with (*a*) insoluble anodes, using a method of regeneration of the tin content of the solution previously described, and (*b*) with tin anodes, using the method recently described by Hansel, which ensures that tin enters the solution entirely as stannic ions; (2) a typical acid tin solution consisting of stannous sulphate, sulphuric acid, and cresolsulphonic acid, with additions of glue and other organic addition agents. Satisfactory plating of strip was obtained by all these methods during the relatively short period of the trials. The acid bath, however, presented important advantages over the alkaline bath, *e.g.*, (*a*) no heating of the solution required as in the case of the alkaline bath, (*b*) lower bath voltage, (*c*) more than double the rate of deposition for the same cathode current density. It appeared that in the acid bath, speeds of electro-tinning comparable with those used for hot-tinning are feasible. But whether the process is likely to be fully satisfactory under industrial conditions depends upon the appearance and quality of the coatings. The latter condition is chiefly considered in Part II. With reference to appearance, the electrodeposited coatings were not comparable in brightness with coatings produced by hot-tinning. Smooth matte deposits were obtained in the alkaline solution, but in the acid solution they varied from coarse matte to a smooth matte, and in special cases were semi-bright, according to the amount of organic addition agent present in the solution. Such coatings require some form of polishing or smoothing process. In order to obtain reliable comparative data, an apparatus was devised which allowed of polishing under controlled conditions, *e.g.*, control of the pressure of the polishing wheel against the specimen, of the speed of the polishing wheel itself and of the transverse movement of the specimen relative to the wheel, &c. Preliminary tests indicated that precipitated

chalk and Vienna lime were the most promising materials for polishing the soft and exceedingly thin tin coatings. It was found, however, that effective polishing involved a loss of from 10 to 13% of the weight of coatings, 0·0001 in. in thickness in the case of smooth matte deposits, 18–20% in the case of the rough matte deposits, and about 7% in the case of the semi-bright deposits. In view of these considerable losses, trials were subsequently carried out to determine the effect of scratch-brushing using the same apparatus. It was found that in the case of smooth matte coatings, the losses were lower than those produced by polishing, to a degree dependent upon the nature of the wire of the scratch brush, *i.e.*, 6–8% with nickel-silver wire, 2–2·5% with steel wire and only 0·5% with brass wire. The scratch-brushing treatment in all cases produced a fairly uniform semi-lustrous surface. The porosity of the tin coatings before and after polishing and scratch-brushing respectively was determined in a number of cases using the hot-water test. These tests were confined to smooth matte deposits. It was found that polishing which produced a 12% loss in weight of this type of coating doubled the porosity of the coating. Scratch-brushing with the steel wire brush which produced a much lower loss, *viz.*, 2·5%, caused a similar increase in porosity, while in the case of the nickel-silver wire brush, which produced a 7% weight loss, the porosity of the coating was quadrupled. It thus appears that scratch-brushing has a greater effect in exposing the basis metal than is produced by polishing, for an equal loss in weight. In the case of the specimens that had been scratch-brushed with brass wire, however, associated with the very low percentage weight loss, the increase in porosity was only slight. It would thus appear that the latter treatment provides a finish which, while not as bright as is produced by the polishing of smooth matte electro-deposited tin coatings, or as is normally produced by hot-tinning, does not markedly affect the protective value of the coating. The actual comparison of the protective value of tin coatings formed by hot-dipping and by electro-tinning, in which the effect of deformation of the coating is also considered, is discussed in Part II.

The Tinning of Steel Strip by Electrodeposition. Part II. The Effect of Deformation on the Protective Value of Hot-Dipped and Electrodeposited Tin Coatings on Steel. D. J. Macnaughtan and J. C. Prytherch. (Electrodepositors' Technical Society and the Iron and Steel Institute, Jan. 13, 1937). From the point of view of the production of tin coatings on steel which are required to be of protective value when the coated steel is subjected to deformation in use, it would appear that the following types of coating are unsuitable, *viz.*: (*a*) "Alkaline" tin deposits; (*b*) bright "acid" tin deposits; (*c*) rough matte "acid" tin deposits. This leaves as an alternative to hot-dipped tin coatings the smooth matte "acid" tin coating and the composite coating produced by electrodeposition of tin from the alkaline bath on a hot-dipped tin coating. From the

technical point of view one of the chief problems in the production of the former type of coating will be the maintenance of the conditions that ensure the formation of deposits of smooth matte ductile tin. This will need careful control, since the structure of the coating is largely dependent upon the presence of suitable amounts of organic agents in the acid bath. The possibility of providing a sufficiently bright appearance to this smooth matte coating without causing a relatively high percentage weight loss of the coating during polishing or scratch-brushing has been discussed in Part I. The production of a composite tin coating by the super-deposition of electrodeposited tin on a hot-dipped or fused tin coating involves a number of special complications. It remains, therefore, to be determined whether the processes involved in producing satisfactory ductile coatings of tin by electrodeposition will prove as economic as the hot-dipping process. It has to be borne in mind that the latter process is likely to be improved and may be made continuous for the coating of wide steel strip.

Black Anodic Coatings on Tinplate and Tin Alloys. R. Kerr and D. J. Macnaughtan. (Journal of the Electrodepositors' Technical Society, 1937, vol. 12 : Sheet Metal Industries, 1937, vol. 11, Feb., pp. 145–150). The authors describe a method of producing black anodic coatings on tin and tin alloys, which is applicable to tinplate and sheet pewter.

Tinplate and Preserved Foodstuffs in France. (Bulletin of the International Tin Research and Development Council, 1937, Feb., No. 5). This bulletin is printed entirely in French. Most of the articles contained in it deal with the preserved foodstuffs industry in France, but the final paper, on tinplate, by the Office Technique pour l'Utilisation de l'Acier, summarises the manufacture and properties of tinplate and the fabrication of tinplate containers, with notes on the sources of supply of tin in French possessions.

The Adhesion of Sprayed Metal Coatings of Zinc, Steel and V2A. T. Everts. (Zeitschrift für Metallkunde, 1937, vol. 29, Feb., pp. 63–66). The adhesion of sprayed metal coatings may be tested by bending, or, better, by tensile tests, the direction of tension being either in the plane of junction or at right angles to it; in the tensile tests sprayed coatings are applied to two pieces of basis metal, and the two coatings are fixed together by means of Wood's metal. Tests showed that with coatings of zinc or steel on steel maximum adhesion was obtained when the basis metal was first sand-blasted with coarse quartz grit and then pickled for a short while in hydrochloric acid. The author describes tests to show the influence of the arrangement and manipulation of the spraying pistol on the adhesion of coatings of zinc, steel and *V2A* steel.

The Effect of Soluble Salts Formed during Ageing on the Scumming of Enamels. R. J. Whitesell. (Journal of the American Ceramic Society, 1937, vol. 20, Mar., pp. 72–75). The author describes an investigation carried out to determine the effect of

soluble salts (predominately compounds of Na_2O and B_2O_3) in the mill liquor on the scumming of enamels. This defect is sometimes called "dulling" and the principal cause is firing at too low a temperature. It is to be understood that this type of scumming is different from that caused by sulphur gases.

Mechanical Drying in Vitreous Enamelling. J. H. Hollows. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1937, vol. 56, Mar. 4, pp. 199–200, 202). The author outlines the principles of drying and discusses the relative merits of different fuels. The relative costs of steam, gas and oil are given. The author also discusses the requirements of an efficient drier for general vitreous enamel work.

Adhesion of Enamel to Steel Produced by the Electrodeposition of $Mo(OH)_3$ on the Steel. C. R. Amberg, H. D. Prior and J. C. Richmond. (Journal of the American Ceramic Society, 1937, vol. 20, Mar., pp. 75–76). It has been found that the deposit of $Mo(OH)_3$ produced when steel is made the cathode in a solution of ammonium molybdate, will cause a white enamel to adhere to the steel. A theory is advanced, as a possible explanation, that the deposited coating prevents the formation of excess iron oxide which would weaken the enamel-iron bond.

Anti-Rusting Paints and Dense Paints. G. Varlan. (Génie Civil, 1937, vol. 110, Feb. 13, pp. 162–163). This is a short abstract of a paper on this subject presented by Rabaté and Courrège before the Institut technique du Bâtiment et des Travaux publiques on Jan. 27, 1937, in which the authors deal with the characteristics of anti-rusting and dense paints used for protecting ironwork against corrosion.

Paints for Military Stores and their Testing. F. J. Peters. (Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Dec. 5, pp. 1469–1474). The Supreme Command of the German Army has put into force a series of terms of delivery for paints to be used on military stores. In this article the author mentions the various paints and other protective media in question, and then deals in more detail with testing methods which have been evolved.

Protective Paints for Steel Bridges. Brodersen. (Bautechnik, 1936, No. 43: Montanistische Rundschau, 1937, vol. 29, Stahlbau-Technik, Mar. 16, pp. 1–2; Apr. 16, pp. 1–4). After touching on the concept of rusting, the author summarises the various types of protective coatings for steel, and then discusses the most suitable paints for the protection of steelwork, with special reference to bridges.

PROPERTIES AND TESTS

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group D, "Subjects of General Importance," were the following :

A. LEON : Measure of the strain of solid materials in various states of stress (theories of fracture and flow conditions).

F. RINAGL : The relations between the results of laboratory tests and practical constructional experience. The measurement of the effect of fitting.

A. WEIGL : The translation of experiences with materials from the laboratory into practice.

R. KÜHNEL : The testing of materials and their verification in practice.

E. LEHR : The practical operating stressing of structural materials and the use of quality values found in the laboratory.

SCHULZ : Experimental errors, scatter and tolerances in testing and acceptance.

Sir R. HADFIELD and S. A. MAIN : Laboratory tests in relation to the serviceability of steel and steel products.

C. C. TEODORESCU : Experimental errors, scatter in results, probability of differences.

M. ROŠ : Relations between the results of tests on materials in the laboratory on the one hand, and the true static load or the fatigue and stability on the other, and their importance in regard to the safety of structures.

F. GUYOT : Industrial radiography by gamma rays.

P. DUWEZ : The hypothesis of the secondary structure applied to the mechanical properties of metals.

J. B. CHLOUPEK : Recent trends in applied physical chemistry.

V. E. PULLIN : Radiology in testing.

M. REINER : The flow-mechanics of dispersed systems.

A. POGÁNY : Measurement of deformations and fissures in tensile, compressive and bend tests by polarisation-microscopical methods.

W. H. FULWEILER : Recent progress in physics and chemistry : their importance for the understanding of materials.

Self-Stresses in Railway Rails. H. Meier. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Mar. 20, pp. 362–363). The self-stresses in railway rails in the longitudinal direction were determined by cutting out thin bars from a section of the rail about 30 cm. long; by carefully measuring the lengths of the thin bars before and after they had been cut out the internal stresses could be

calculated. The author distinguishes between self-stresses arising from cooling only and those set up in the straightening process. The results are presented and discussed.

Two- and Three-Dimensional Cases of Stress Concentration, and Comparison With Fatigue Tests. R. E. Peterson and A. M. Wahl. (Transactions of the American Society of Mechanical Engineers, 1936, vol. 58, pp. A15–22). The authors present the results of a study of some two- and three-dimensional cases of stress distribution with particular reference to shafts having fillets or transverse holes, these being of considerable practical importance. To determine the stress-concentration factor k_t in such cases, strain measurements were made, using a specially developed extensometer with a gauge length of 0·1 in. The results of these strain measurements indicate that for shaft fillets in bending (three-dimensional case) the stress-concentration factor k_t is little different from the values obtained photo-elastically on flat specimens having the same r/d ratio (a two-dimensional case). A comparison of these values of k_t (both for shafts with fillets and with transverse holes) with data from fatigue tests leads to the following observations: (1) In some cases fatigue results are quite close to theoretical stress-concentration values. (2) Fatigue results for alloy steels and quenched carbon steels are usually closer to theoretical values than are the corresponding fatigue results for carbon steels not quenched. (3) With decrease in size specimen, the reduction in fatigue strength due to a fillet or hole becomes somewhat less; and for very small fillets or holes the reduction in fatigue strength is comparatively small. (4) Sensitivity factors determined for small specimens should not be applied to the design of machine parts regardless of size.

The Rate of Growth of Fatigue Cracks. A. V. de Forest. (Transactions of the American Society of Mechanical Engineers, 1936, vol. 58, pp. A23–25). The author discusses the resistance of metal to the propagation of cracks, and points out that in the accepted method of fatigue testing the results are not conclusive because there is no distinction between (1) the load and the number of repeated stresses required to start cracks and (2) the load and the number of reversals needed to propagate the cracks to failure. The investigation reported in the paper was undertaken to determine (*a*) the stress and number of reversals required to start a fatigue crack, and (*b*) the resistance of the material to the effect of a fatigue crack once it had been formed. The tests reported were conducted on annealed cold-rolled low-carbon steel bars with various finishes. The author presents data on the rate of progress of the cracks and on the size of the cracks, the latter of which was determined by magnetising the bars and inspecting them with finely divided iron oxide in a bath of kerosene.

Increasing the Fatigue Strength of Press-Fitted Axle Assemblies by Surface Rolling. O. J. Horger and J. L. Maulbetsch. (Transactions of the American Society of Mechanical Engineers, 1936,

vol. 58, pp. A91–98). The authors present test data on 2-in. axles showing how the fatigue strength in reversed bending is reduced to between one half and one third by the mere presence of a press-fitted member, and how such a press-fit assembly may be made more than twice as strong by surface rolling the axle at the press-fit seat. Further tests are given to show that the increased strength obtained by surface rolling is due principally to strain hardening of the material at the surface of the axle. The weakening action of press fits is due to high stress concentration and rubbing corrosion localised near the ends of the pressed-on hub, and in this respect surface rolling produces a layer of material having a resistance which is considerably increased in the region of this local weakness. Additional data are presented to show that plain cylindrical specimens of the usual 0·3 in. dia. give 10 to 15% increased fatigue strength over that given by specimens about 1 in. in dia., and to show that there should be no difference in fatigue strength between a cantilever- and a beam-type specimen of the same diameter and of the same steel.

Industrial Shape-Strength Investigations. S. Berg. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Apr. 24, pp. 483–487). The fact that the fatigue strength of structures is dependent not only on the material used and the cross-section stressed but also on the shape of the article has led to the introduction in industry of "shape-strength" tests (*Gestaltfestigkeitsversuchen*). In these tests either the absolute or relative fatigue strength of the structure or the distribution of stress in it is determined, in order to discover whether greater safety can be obtained by using stronger material or by altering the design. The fatigue strength is determined in alternating stress tests and the stress distribution by stress measurements on models or finished parts. The author describes and discusses the alternating-stress testing of a variety of industrial structures and parts.

The Influence of Vibrations on the Mechanical Properties of Structural Materials. G. Welter. (Revue Technique Luxembourgeoise, 1937, vol. 29, Mar.–Apr., pp. 34–39). (*See* G. Welter and A. Bukalski, Journ. I. and S.I., 1937, No. I., p. 177 A).

Recovery of Steels from Acid Brittleness. S. Coppick. (Wire and Wire Products, 1937, vol. 12, Feb., pp. 67–71, 108; Mar., pp. 123–128). The various theories advanced by other workers for the mechanism of the diffusion of hydrogen in steel are reviewed, and the author describes an investigation having for its object: (1) the determination of the rate of the recovery of the toughness of steels after an acid treatment to induce embrittlement; (2) to find out how this rate varies with temperature, chemical composition, and structure; and (3) to find for different steels the best heat treatment, which will result in an efficient rapid rate of recovery of toughness with the minimum amount of surface oxidation. A Sankey testing machine was used in determining the toughness of

the specimens. The results show that in the first place there is a rapid constant rate of recovery, which extends up to a critical, or commercially feasible point. This is followed by a very slow rate of recovery range, which is relatively uneconomical, except in special cases where the quality of the product desired necessitates complete dehydrogenation. Generally, low-carbon steels can be effectively or at least sufficiently recovered from embrittlement for ordinary purposes by baking at 100° C.; there are, however, exceptions to this rule. Varying the manganese content in low-carbon steels has no perceptible effect on the recovery. High-sulphur, high-manganese contents in a low-carbon steel make baking at 100° C. commercially uneconomical. At 200° C., however, these steels may be efficiently baked. Small amounts of cold-work have very little effect on the recovery of toughness of a steel. It was confirmed that the higher the carbon content of a steel the less was the recovery on baking. The indication is that the rate of recovery of steel from acid embrittlement varies with the diameter to a great extent. High-carbon steels cannot be efficiently baked at 100° C. The longer the time of pickling, the more is the embrittlement induced, but the steel follows the same path of recovery, except that it begins to recover from a lower value of toughness.

The Relative Wear of Some Hard Metals. R. B. Freeman. (Metal Progress, 1937, vol. 31, Mar., pp. 281–284). The author presents the results of an investigation of the sliding wear resistance of stellite, a chromium-aluminium-molybdenum steel, a case-hardened steel, a white cast iron, an engine-block casting and an alloy cast iron. The results of tests on these materials in various combinations are shown.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following:

F. Le Chatelier: Wear resistance of steels and methods of testing.
H. Meyer: The analysis of the wear process as an essential of the wear-testing of metals.
F. P. Bowden and T. P. Hughes: The surface temperature of sliding metals and its influence on flow and wear.
H. E. Smith: Experiments on the abrasion of metals.
A. Pohl: Special types of wear of rails and tyres on the Austrian Federal Railways and counter-measures taken.
S. Saito: The reduction of abrasion by compound contact pieces or powder.
M. Suzuki: An investigation of abrasion in cast iron.
S. J. Rosenberg: Oxide films as a protection against wear.

On the So-Called Temperature Dependency of Spontaneous Magnetisation. K. Honda and T. Nishina. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Nov. pp. 480–488). After outlining briefly the concept of spontaneous magnetisation,

the authors give an account of their experiments directed to the measurement of the true dependency of the spontaneous magnetisation of an iron single crystal on the temperature. They conclude that expressions for the spontaneous magnetisation given by Weiss, by Heisenberg and by Hironé and Hikosaka really give the temperature dependency of induced magnetisation, and that success in deducing theoretically the temperature dependency of spontaneous magnetisation has not yet been attained.

On the Effect of Stretching and Twisting on the Discontinuous Process of Magnetisation in Nickel, Iron, and Nickel-Iron Alloys. J. Ôkubo and M. Takagi. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Nov., pp. 426–479). The authors have studied the effect of stretching and twisting on the discontinuous process of magnetisation in wires of nickel, of iron and of nickel-iron. The principal results obtained were as follows: (1) The discontinuities are mainly distributed in the steep portion of the hysteresis loop, and the correspondence between the steepness of the slope and the distribution of discontinuity is very close. (2) There is a linear relation between the values of $\Sigma H \delta I_d$ (I_d is the intensity of magnetisation due to the discontinuous process at the field intensity H) and the areas of the hysteresis loops observed when the materials were tested under the application of various tensions and twists. (3) Investigation of the relation between the change in maximum intensity of magnetisation and the total sum of the discontinuities observed during a half cycle of the hysteresis loop showed that there were three cases: When applying increasing stretching stress, the above two quantities (*a*) increase or (*b*) decrease according to whether the magnetic elongation of the material is positive or negative; increasing the twisting stress results in (*c*) a decrease of the maximum intensity of magnetisation and an increase in the discontinuities, irrespective of whether the magnetic elongation of the material be positive or negative. The authors show that all the observed results can be explained by considering the distribution of the magnetic axes of the atoms of the material under tension to be of a prolate or oblate-spheroidal type.

Development of Nickel-containing Permanent Magnets. (Nickel Bulletin, 1937, vol. 10, Mar., pp. 49–52). The development of nickel-aluminium and nickel-aluminium-cobalt magnet steels is reviewed, and particulars are given of some recent applications.

A Single Strip Core-Loss Tester for Electrical Sheets. B. M. Smith. (Iron Age, 1937, vol. 139, Mar. 25, pp. 30–33). The author describes a single strip core-loss tester, which is claimed to have certain advantages over other types. With this tester the actual quality of a single strip is determined instead of the average quality of a large number of strips in parallel.

A Direct-Load Creep-Test Machine. J. J. Curran and F. H. Morehead. (Proceedings of the American Society for Testing Materials, 1936, vol. 36, Part II., pp. 161–169). The authors

describe a direct-load creep-test machine, in which a convection type of furnace is used. The atmosphere of the furnace is continuously recirculated around the specimen and shackles, heat being applied at a remote point by passing the circulating air through a heating chamber. The test and calibration specimens used conform to those described by Gillett and Cross (Metals and Alloys, 1933, vol. 4, July, p. 91). Temperature control is achieved by means of a chromel-alumel thermocouple inserted into a drilled hole extending axially through the threaded end to the shoulder, just outside the fillet. This couple, connected to a suitable potentiometer controller, with provision for anticipatory action, increases and decreases the current in the furnace winding and maintains the temperature of the specimen constant within very narrow limits. Another couple, located similarly in the other end of the specimen, is connected to a potentiometer recorder and furnishes a continuous record of temperature fluctuations within the specimen. The method of loading is shown. A welded framework of structural steel rests on concrete piers which are independent of one another. The test specimens and furnaces are supported directly on the framework. Space has also been provided for testing a specimen with a 24-in. gauge length when and if a means can be provided for maintaining a uniform temperature in a specimen of this length. The convection furnace appears to offer a means of attaining uniformity in such unconventional specimens. A calibration station is used for calibrating new furnaces, thus avoiding loss of time at testing stations. While this type of creep-test machine has one marked disadvantage, in that it occupies considerable floor space, it has certain advantages over the lever type. A lever system oscillates with each slight change in the temperature of the furnace, due to change in length of the specimen and shackles. The direct-load machine requires no levelling of the beam, nor can it introduce errors due to eccentric loading. It is essentially frictionless.

High-Temperature Properties of Cast and Wrought Carbon Steels From Large Valves for High-Temperature Service. H. C. Cross and F. B. Dahle. (Transactions of the American Society of Mechanical Engineers, 1936, vol. 58, pp. 103–113). The authors describe the short-time tensile, impact and creep properties at 750°, 850° and 950° F. of two forged and two cast carbon steels taken from finished valve bodies and tees. The two cast steel and one forged steel contained about 0·35% carbon and one forged steel contained about 0·27% carbon. Definite differences in structure were found. One cast steel as supplied by the manufacturer showed a spheroidised structure, while the other three steels were pearlitic. Results of the creep tests are compared with the structures, and results of the short-time tensile tests and impact tests at room and elevated temperatures are given.

Alternating Tensile Tests on Steel at Temperatures up to 600°. M. Hempel and H. E. Tillmanns. (Archiv für das Eisenhütten-

wesen, 1937, vol. 10, Mar., pp. 395–403). In alternating tensile tests on three different steels (plain carbon steel, molybdenum steel and chromium-nickel-tungsten steel) at raised temperatures, the extension of the material under alternating stress was particularly observed. Under loads approximating to the fluctuating-stress fatigue strength, extensions of up to 13% and rates of extension of 200–400 $\times$ 10^{-4}% per hr. were obtained in the latter part of the fatigue test lasting for 1·8–2·2 $\times$ 16^6 stress reversals; the fluctuating-stress fatigue stress values obtained by the Wöhler method at raised temperatures cannot, therefore, be used in the design of structures. A mechanical-optical appliance for recording the flow under alternating load was developed and applied in comparison tests at raised temperatures under static loads (creep tests), under fluctuating loads alternating 50 and 500 times per min., and under loads corresponding to the creep limit and the 0·2% proof stress. In general, the rate of extension in the creep test was the same as that in the alternating-load test, though in a few cases it was slightly greater and in one case less. It appears that the extension under alternating load is determined by the upper load limit, and that the rate of load-alternation in the lower ranges has no influence on the changes of extension for the materials tested.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following:

H. J. Tapsell: The phenomenon of creep recovery.
C. L. Clark and A. E. White: The mechanism of the creep of metals.
A. Nadai: Creep of metals.
L. Gottignies: The resistance to plastic deformations of steels working at raised temperatures.
R. Ludwig and H. Wüstl: Short-time test of the Poldihütte for the determination of the creep strength of steel, also method for evaluating the time-extension curves.
A. Pomp: Testing the behaviour of metals under mechanical stresses at raised temperatures.
R. W. Bailey: Creep and engineering design.
W. H. Hatfield: Creep as occurring in different steels under service conditions.
J. J. Kanter: Interpretation and use of creep results.
C. E. MacQuigg: Effect of temperature on the properties of steels.
G. Welter: Bending and tension-compression endurance tests with observations on temperature effects.
V. I. Garcia: Contribution to the study of the impact tensile testing of metals.
F. E. Bash: Testing high endurance oxidation-resistant alloys.
S. L. Hoyt and M. A. Scheil: Life testing Smith alloy No. 10.

Use of Steels at Elevated Temperatures. R. T. Rolfe. (Iron and Steel Industry, 1936, vol. 10, Nov., pp. 143–147; Dec., pp. 187–191). The author surveys published information on steels for use in steam power plant and considers in some detail the effect of combined stress and temperature on carbon and alloy steels. Various methods of creep testing are dealt with.

Properties of the Material of Mannesmann Tubes at High Temperatures. N. Orlov and M. Miagkov. (Stal, 1936, No. 7, July, pp. 90–97). The paper contains data obtained in the investigation of ten seamless tubes from the K. Liebknecht works. Chemical composition, metallographical structure, the usual mechanical properties, the creep velocity under stress and the impact bending strength were investigated. The mechanical tests were made at temperatures up to 700° C., with particular reference to the conditions which these tubes have to sustain in the oil industry, especially in the cracking process. (In Russian).

Grey Cast Iron. J. W. Bolton. (Foundry, 1936, vol. 64, Sept., pp. 32–33, 80; Oct., pp. 44–48; Nov., pp. 32–33, 79; Dec., pp. 44, 47; 1937, vol. 65, Jan., pp. 46–48, 51–52; Feb., pp. 46, 50, 52). The conclusion of a series of articles in which the author discusses some of the general engineering properties of grey cast iron. (*See* Journ. I. and S.I., 1937, No. I., p. 36 A).

Some Applications of "Ni-Tensyl." (Mond Nickel Co., Ltd., Bureau of Information on Nickel, 1937, Publication B 30). Some examples of the uses of "Ni-Tensyl," a high-duty nickel cast iron, collected from American sources, are summarised and illustrated.

High-Duty Alloy Cast Iron. A. B. Everest. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 1, pp. 265–267, 273). Some notes are given on the production, heat treatment and properties of high-duty cast irons.

Modern Improved Cast Irons. J. W. Donaldson. (Metal Treatment, 1937, vol. 3, No. 1, Spring issue, pp. 8–12, 15). A review of developments in the production of high-duty, alloy, heat-resistant and corrosion-resistant cast irons.

New Ferrous Alloys Obtained By Use of Boride Crystals. M. C. Smith. (Steel, 1937, vol. 100, Mar. 29, pp. 46–47). The author deals with the addition of boride crystals to ferrous alloys, and shows the effects of this material on the physical and corrosion-resisting properties of cast iron, mild steel and tungsten-bearing steel.

Modern Developments in Constructional Steels. (Metal Treatment, 1937, vol. 3, No. 1, Spring issue, pp. 39–42). An abridged English translation of an article by E. H. Schultze in which the author reviews the evolution of constructional steels in Germany. The original article appeared in Maschinenbau der Betrieb.

The Nickel-Copper High Strength Steels for Weld Construction. A. E. Gibson. (Welding Journal, 1937, vol. 16, Feb., Welding Research Supplement, pp. 2–6). The author describes the properties

of several nickel-copper steels, and points out their advantages for welding construction.

Aircraft Engine Materials. J. B. Johnson. (Society of Automotive Engineers, Jan., 1937 : Heat Treating and Forging, 1937, vol. 23, Feb., pp. 75–79). Particulars are given of the various types of ferrous materials used in engine construction in the American aircraft industry.

Materials—With Reference to Steel. T. Swinden. (Symposium on Research in Relation to the Motor Vehicle : Proceedings of the Institution of Automobile Engineers, 1937, vol. 31). The author uses the provisional specifications issued by the Society of Motor Manufacturers and Traders as a background on which to draw attention to the trend of development in the types of steel used in the more important parts of automobile construction. Attention is directed to the manganese-molybdenum and chromium-molybdenum steels used for crankshafts, and some notes are included concerning various methods of surface hardening and the dangers attached to cold straightening. The properties of the accepted types of valve steels are enumerated and the relative merits of air-hardening, case-hardening and direct-hardening steels for gears are discussed, with particular reference to the various methods of case-hardening and to the importance of the control of grain size. Reference is also made to springs and the coating of spring plates with the dual object of reducing corrosion and interleaf friction. The concluding section of the paper deals with steels for chassis and body construction.

Advantages of Alloy Steels. A. L. Boegehold. (Metal Progress, 1937, vol. 31, Mar., pp. 265–269). The author discusses the applications of alloy steels to automobile construction.

Plain Carbon Steel—its Utility for Automobiles. A. L. Boegehold. (Metal Progress, 1937, vol. 31, Feb., pp. 147–152). The author discusses the inherent limitations of heat-treated carbon steels, even when of the best commercial quality, as far as their applications to important automobile parts are concerned.

Physical-Property Uniformity in Valve-Body Steel Castings. A. E. White, C. L. Clark and S. Crocker. (Transactions of the American Society of Mechanical Engineers, 1936, vol. 58, pp. 643–647). The authors describe an extensive investigation of the physical properties of specimens cut from various sections of large welding-end valve bodies made of carbon-molybdenum cast steel. Macrosections, impact values and density determinations are presented in addition to the usual tensile properties. The results indicate that the welding ends are the soundest part of the valve body, and that sections cut from the valve body as close as possible to the welding ends have physical properties commensurate with those obtained from conventional separately and integrally cast test bars. Evidence of rather general porosity was disclosed by the macrosections from the thicker-walled portions of the bodies and in the bonnet flange, with consequent low ductility values for

some of the tensile specimens from these locations. While this condition was considered fairly acceptable when allowance was made for the greater metal thickness in these sections, the investigation showed these to be the regions where improvements could be effected through further development of casting procedure.

Recent Developments in Rock Drill Steel. G. B. O'Malley. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1936, No. 103, Sept. 30, pp. 309–329). The author reviews developments in the steels used for rock drills—carbon steels, alloy steels, lined steels, tapered steels—and in shop methods of cutting, forging, hot-milling, hardening and shanking; he concludes with a note on detachable bits. The lined steels consist of hollow steels with a lining of carbon steel or rustless iron, the purpose of which is to resist corrosion-fatigue. " Straight-line " hardening is an improvement of the older method, in which the bit was heated to a depth of $\frac{3}{4}$ in. in an open furnace and then quenched in water to a depth of $\frac{1}{4}$ in.; the resulting microstructure consisted of a zone of martensite (with maximum depth at the reaming edge), succeeded by a zone of troostite and then the unaltered sorbite of the forged steel, and this gave rise to a tendency for fracture to occur at the wings and for the development of a convex drilling face. For straight-line hardening the bit is heated end-on by flames emerging from an aperture of slightly small diameter than itself; the depth of heating is only $\frac{1}{4}$ in., and the bit is then fully quenched, in water for carbon and oil for alloy steels. The martensitic zone is practically uniform in depth and is succeeded by the unaltered sorbitic structure with little or no intermediate troostite; bits hardened in this way maintain the chisel edge and the wings longer than after the older hardening treatment.

High-Tensile Cap Screws Made from Low-Carbon Steel Cold Drawn at the Header. F. W. Gaines. (Wire and Wire Products, 1937, vol. 12, Mar., pp. 141–143). The author presents the results of tests carried out to determine the possibility of making high-tensile unheat-treated bolts and cap screws by extrusion in header dies or by controlled cold-drawing prior to heading.

Stress and Deflection of Helical Springs. R. F. Vogt. (Transactions of the American Society of Mechanical Engineers, 1936, vol. 58, pp. 467–475). The author has developed new stress formulæ for calculating stresses in helical springs. These formulæ are for use in determining the stresses in helical springs of circular-bar and rectangular-bar cross section. They include the proper consideration of bar curvature, pitch angle and bending stress, but nevertheless they are extremely simple. The author makes the design calculations for tension and compression helical springs to show the application of the formulæ he has developed.

Wire Ropes for Mines. M. A. Hogan. (Bulletin of the Institution of Mining and Metallurgy, Apr., 1937, No. 391). The author discusses the properties of wire ropes used at mines in relation to

the conditions under which they work. He deals with winding conditions, and gives brief notes on the manufacture and properties of wire ropes.

Wire-Rope Problems. B. P. Haigh. (Proceedings of the South Wales Institute of Engineers, 1937, vol. 52, Feb. 4, pp. 327–357). After some notes on the history of wire, the author discusses the structure of drawn patented steel wire, the fracture of wires in service, and fatigue tests on wire, describing various testing machines that have been developed and reviewing results obtained. He then turns to the problems set by the passage of wire ropes over pulleys. Finally, he refers to corrosion-fatigue in wires; it is of historical interest that this phenomenon was discovered during an investigation of the very short lives at first obtained from the ropes by which the "paravanes" and "otters," used as a protection against moored mines, were towed by ships during the World War.

Spring Steel Castings Ride the Rails. R. L. Collier. (Metal Progress, 1937, vol. 31, Feb., pp. 181–183, 198). The author discusses developments in the use of steel castings for locomotive and railroad car construction in America.

Investigation of Scabs on the Surface of Railway Tyres and their Elimination. N. Shapov and V. Kislick. (Stal, 1936, No. 6, June, pp. 60–66). The investigation of 240 tyres taken out of service because of the occurrence of scabs on their surfaces showed that the formation of scabs is due to silicate slag inclusions in the shape of long branched chains. (In Russian).

METALLOGRAPHY AND CONSTITUTION

Comparative Properties of Metallic Surfaces Polished Mechanically and Electrolytically. P. A. Jacquet. (First International Electrodeposition Conference, London, Mar. 3–4, 1937). Metallic surfaces polished by the usual procedure, involving mechanical treatment, and by the electrolytic process have quite different structures. Mechanically-polished surfaces show no crystalline properties; apart from the superficial, probably amorphous, layer, there exists a more or less thick zone of micro-crystals, having no resemblance to the crystals of the metal. The properties of such a surface are bound up with this special structure, and are not specific to the metal. Electrolytic polishing—really a type of etching—allows the properties of the crystal faces to be studied.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following :

M. NIESSNER : Microchemical surface investigation of metallic materials.
A. R. MATTHIS : The determination of the uniformity of a coating of zinc.
W. H. DEARDEN : The preparation of specimens for macro- and micro-examination.
KÖSTER : Progress in the metallographic microscope.
F. F. LUCAS : Progress in microscopy.
M. C. NEUBURGER : Precision measurement of lattice constants.
U. DEHLINGER : X-ray interference investigation in metallography.
A. J. BRADLEY : Quantitative metallographic X-ray technique.
E. SCHMID : Crystalline condition and properties of materials.
H. J. GOUGH : Characteristics of the deformation and fracture of metals as revealed by X-rays.
G. I. TAYLOR : Crystal lattice and mechanical properties.
F. KIRCHNER : The application of electron interference to the study of metal surfaces.
G. I. FINCH : The study of metal films and surfaces by electron diffraction.
G. AMINOFF : Electron interference in the study of the oxidation of crystal surfaces.
W. G. BURGERS : Electron-optical observation of metal surfaces.

Magnaflux Inspection of Pressure-Vessel Welds. J. W. Yant. (Mechanical Engineering, 1937, vol. 59, Mar., pp. 145–146). The

application of the magnaflux test to the examination of pressure-vessel welds is discussed.

Detection of Fatigue Cracks by Magnaflux Method. T. C. Rathbone. (Mechanical Engineering, 1937, vol. 59, Mar., pp. 147–152). The author discusses the fatigue failure of machine parts and describes the detection of fatigue cracks by the magnaflux method. Typical examples of fatigue cracks are shown.

Magnaflux Inspection of Boiler Drums and Unfired Pressure-Vessels. R. F. Cavanagh. (Mechanical Engineering, 1937, vol. 59, Mar., pp. 153–155). The author describes procedure for the detection of cracks in boiler drums and pressure-vessels by the magnaflux method.

Two Examples of the Application of X-Rays to Metallurgy. R. Michaud. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Feb., pp. 195–203). The author describes the results of two investigations carried out with X-rays. In the first, Clark's law regarding transformer sheets was checked. This law states that for such sheets with 3–4% of silicon, the better the magnetic properties of the sheet the larger and fewer are the X-ray diffraction spots on the Laue diagram obtained. The author concludes from his study that the law does not always hold good, for he presents a whole series of sheets of very similar compositions in which neither the size of the crystals nor their regularity of shape determine the magnitude of the hysteresis losses. The second study concerns the suppression by annealing of the orientation and deformation of the crystals in rolled commercial aluminium.

The Principles of the Radiographic Process. J. T. Norton. (American Society for Testing Materials, Symposium on Radiography and X-ray Diffraction Methods, 1936, pp. 3–24). The author discusses the relations existing between the various factors entering into the production of a successful radiograph.

Foundry Applications of Radiography. E. Cook. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 25–52). The author presents data collected from five laboratories concerning the use of radiographic examination for the metallurgical control and inspection of a wide range of castings. The relative definition of ordinary defects upon the films varies with the general laboratory technique, with the type and location of the defect with respect to the direction of the beam and especially with the thickness of the section. The more familiar imperfections readily interpreted from the films are shrinkage cavities, flocculent shrink, blow-holes, cracks, inclusions and pronounced dendritic formations. The employment of small-scale pilot castings for the study of homogeneity control and the attainment of directional solidification in production is described in detail.

Radiography in the Welding Shop. J. C. Hodge. (American Society for Testing Materials, Symposium on Radiography and

X-Ray Diffraction Methods, 1936, pp. 53–91). The author describes technique for the X-ray examination of welds, and outlines the development of equipment for that purpose.

Miscellaneous Applications of Radiography and Fluoroscopy. H. E. Seeman. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 92–115). The author discusses the general conditions for the application of the radiographic and fluoroscopic methods of X-ray examination to a number of industrial products and materials.

Gamma-Ray Radiography and Its Relation to X-Ray Radiography. N. L. Mochel. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 116–155). The technique of gamma-ray radiography is described, and a number of examples of the use of the method are cited. In dealing with the relation of gamma-ray radiography to X-ray radiography the author discusses such matters as thickness, sensitivity, scattering and fogging, contrast, speed, portability, cost and reliability.

The Problem of Radiographic Inspection. H. H. Lester. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 156–190). Radiographic acceptance tests set standards of metal soundness that are usually higher than those set by other methods of testing, and the author points out the need for a better understanding of the tests and their significance on the part of both producers and consumers.

X-Ray Diffraction Equipment and Methods. C. S. Barrett. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 193–229). The author describes installations for diffraction work, and offers suggestions regarding suitable instruments for various practical applications. The X-ray method of determining solid solubility by lattice parameter measurements is explained and illustrated. Consideration is given to the various factors influencing such measurements, and to the application of lattice parameter measurements to the study of the age-hardening of alloys. Examples are given of the method of determining the depth of cold-working from a machining operation and the amount of cold-work that occurs as a result of alternating stresses in a fatigue specimen; it is pointed out that diffraction patterns do not provide a direct indication of impending fatigue failure. An explanation is also given of the determination of internal and applied stresses in the surface fibres of a metal by the use of back-reflection cameras.

The Constitution of Alloys. K. R. Van Horn. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 230–283). The author discusses the use of X-ray diffraction methods for studying the constitution and structure of alloys, and reviews the work of various investigators.

Chemical Analysis by X-Ray Diffraction Methods. W. P. Davey. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 284–301). The author discusses, in non-technical language, the salient advantages of the X-ray crystal structure method for the identification of crystalline materials.

Application of X-Ray Methods to Problems of Cold-Work, Preferred Orientation and Recrystallisation. J. T. Norton. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 302–323). X-ray diffraction methods can be used to advantage in the observation and interpretation of the structural changes brought about by cold-working. In general, the effects of cold-work on a polygrained metal may be divided into three classes. The first is concerned with the distortion of the crystal lattice which is the basis of the structure of individual grains. This distortion is associated with small deformations of the sample, but the influence upon the properties may be considerable. The second effect is the fragmentation of the grains which is associated with larger deformations. Regions of the sample which were originally single grains are transformed by a process of shear into smaller fragments which usually are displaced not only by translation but also by rotation. The third effect which becomes marked at large deformations of a directional nature, such as rolling or drawing, is called preferred orientation. It is a tendency for all of the crystal fragments to align themselves in a definite way regardless of the original orientation of the grains, and results in directional properties of the sample. Several typical examples of X-ray diffraction methods for investigating the effect of cold-work are cited.

The X-Ray Determination of Particle Size. G. Harvey Cameron and A. L. Patterson. (American Society for Testing Materials, Symposium on Radiography and X-Ray Diffraction Methods, 1936, pp. 324–338). The X-ray method of measuring particle size is applicable to particles from approximately 0·00001 cm. in diameter down to the smallest which have a crystalline structure. These particles give rise to diffraction lines broader than those ordinarily found in the "powder" photograph. Measurements of particle size are based on some theoretical formula which connects the breadths of the diffraction lines with the size of the particles. The various formulæ proposed are reviewed with emphasis on the underlying assumptions, since the latter have not always received proper attention. Possible sources of error, such as non-uniformity of the sample and distortion of the crystal lattice, are discussed briefly. Experimental attempts to test the formulæ and apply them to such materials as colloidal metal catalysts, cellulose, rubber and activated charcoals are described. On account of the imperfect state of the theory, absolute values of the particle size may not be reliable. Relative values can be obtained with an accuracy of about

10% under favourable conditions. A selected bibliography of about 30 references is included.

The Range of Validity of the Hume-Rothery Law. H. Witte. (Metallwirtschaft, 1937, vol. 16, Mar. 5, pp. 237–245). According to Hume-Rothery's law, a phase with a particular structure makes its appearance in an alloy when the concentration of valency electrons reaches a certain value, the latter varying with the phase in question. The present author reviews knowledge extant of a large number of binary alloys, including some of iron, to show the range of validity of this law.

Effect of Small Deformations on the X-Ray Fine Structure. E. Martin. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Mar., pp. 415–417). The change of the X-ray photograms of annealed wires of aluminium, copper, steel and nickel with increasing tensile load was investigated by the Debye-Scherrer method. It was found that it was possible to recognise when the elastic limit was exceeded; in iron the yield point could be recognised with certainty. In further tests, changes in the photograms of annealed specimens of steels St.37 and St.52, of cold-worked test-pieces of St.52 and of heat-treated tyre-steel specimens with the number of impacts in the impact fatigue test were examined. The Debye rings of annealed specimens progressed proportionately up to the fatigue failure in the same way as in the normal tensile test, though not to the same extent. With cold-worked test-pieces the previously overlapping $K\alpha$ doublets separated into $K\alpha_1$ and $K\alpha_2$ rings. With the heat-treated tyre steel there was no notable change in the originally confused photogram as the number of impacts increased.

Which Grain Size? C. H. Herty, jun., D. L. McBride, and E. H. Hollenback. (Transactions of the American Society for Metals, 1937, vol. 25, Mar., pp. 297–314). The authors discuss the effect of grain size on hardenability. They point out that the size of grain which determines hardenability is that present in the steel at the moment of quenching, and not that determined under conditions quite different from those encountered in normal heat-treating operations. It is experimentally shown that for a given analysis, hardness penetration is a direct function of the grain surface area per unit volume of steel at the quenching temperature. The surface area is a function of the grain size of the steel. Surface hardness is shown to be essentially independent of the grain size, provided that the critical cooling rate is exceeded. This rate is higher for fine-grained than for coarse-grained steels. If the cooling rate is decreased below the critical value, due to gas or scale interference with heat transfer, soft spots will occur.

The Estimation, Effect and Control of Grain Size in Steel. (Metal Treatment, 1937, vol. 3, No. 1, Spring issue, pp. 18–26). An abridged English translation of a paper by E. Houdremont and H. Schrader the original of which appeared in Stahl und Eisen, 1936,

vol. 56, Nov. 26, pp. 1412–1422. (*See* Journ. I. and S.I., 1937, No. I., p. 88 A).

Recent Crystallography. Sir W. Bragg. (Proceedings of the Royal Institution of Great Britain, 1936, vol. 29, Part III., pp. 484–495). The author is principally concerned with advances in knowledge of the crystallography of organic compounds, but he refers to the use of X-rays to observe the breakdown of crystallites in mild steel when undergoing fatigue and as a means of examining the crystal structure of nitrided steel.

On the Change of Transformation Points of Chromium Steels due to Cooling Conditions. T. Murakami and H. Kishimoto. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Dec., pp. 726–744). Variations of the transformation points of chromium steels (less than 27·8% of chromium and 1·55% of carbon) due to changes in the cooling conditions were determined by magnetic analysis; the relation between the composition and the transformation points is shown diagrammatically. With the same specimen the extent of the normal transformations (Ar_2, Ar_{12}) decreases with decreasing temperature, whilst the extent of the lower transformation (Ar″) increases with increasing cooling velocity and heating temperature. For constant carbon contents the lowering of the transformation points becomes easy with increasing chromium content, until the point is reached at which the γ-phase no longer appears, when the depression of the transformations does not occur. For constant chromium contents, the depression becomes easy with rising carbon content, up to a limit, beyond which it becomes difficult. The completely depressed Ar″ point occurs at lower temperatures as the carbon content rises. By raising the heating temperature or increasing the cooling velocity, the depression of transformations will take place in low-chromium specimens. In samples with 14–26% of chromium, the transformations are depressed in high-carbon alloys but not in those with low carbon contents. In specimens containing more than 26% of chromium the transformation points are not lowered at all.

Changes of Mechanical Stresses during the Austenite-Martensite Transformation. E. Scheil and W. Thiele. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Apr., pp. 477–480). At the moment of the austenite-martensite transformation steel is in a condition of enhanced plasticity. In the transformation range, stresses are reduced almost to zero. The deformability is not unlimited, however, but amounts only to a certain value which depends on the stress. Even in the transformation range, therefore, steel possesses the ability to work-harden. The increased plasticity of steel is the cause of the self-stresses in hardened steel. The so-called transformation stresses depend primarily on the temperature difference between the outside and the inside in the transformation range; the greater this is, the greater are the remaining self-stresses.

Alloys. W. L. Bragg. (Journal of the Royal Society of Arts,

1937, vol. 85, Mar. 26, pp. 431–447). The author discusses the nature of the metallic state, alloy phases, the origin of phase patterns and atomic distribution in phase patterns.

Formation of Metallic Nitrides by Melting. D. Séférian. (Chimie et Industrie, 1937, vol. 37, Mar., pp. 426–438). The author describes the effect of nitrogen on molten iron. He first presents a study of the iron-nitrogen system and proposes a new constitutional diagram for the field of low concentrations. He then shows the influence of nitrogen on the mechanical properties and the structural hardening of iron and steel. In conclusion he discusses the practical implications of the iron-nitrogen diagram.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following:

M. HANSEN: Progress relative to the constitutional diagrams of iron.

W. KÖSTER: Progress in methods of investigating constitutional diagrams.

CORROSION OF IRON AND STEEL

Corrosion Loss of Steel. (Iron and Coal Trades Review, 1937, vol. 134, Apr. 2, pp. 605, 606). An abridged English translation of the paper by K. Daeves and K. Trapp (*see* Journ. I. and S.I., 1937, No. I., p. 248 A) in which the authors present a further estimate of the annual loss of steel by corrosion in Germany. The authors' analysis is a direct continuation of that made by G. Schaper (*see* Journ. I. and S.I., 1937, No. I., p. 150 A).

The Fight against Corrosion in the Netherlands. G. Batta. (Métaux et Corrosion, 1937, vol. 12, Feb., pp. 35–39). A summarising review of researches on corrosion and its prevention being carried out by various organisations in Belgium and Holland.

Mechanism of the Corrosion of Metals. E. C. Rollason. (Welder, 1937, vol. 9, Feb., pp. 53–58, 61). The author outlines the mechanism of the corrosion of metals in acids and other media, and discusses the characteristics of a few metals used for protecting iron and steel.

Some Aspects of Metallic Corrosion. U. R. Evans. (Institution of Engineers and Shipbuilders in Scotland, Mar. 9, 1937 : Iron and Coal Trades Review, 1937, vol. 134, Mar. 26, p. 573). The author discusses the effect of composition, particularly sulphur, on the corrosion of iron, and describes laboratory tests carried out at Cambridge University.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following :

E. HOUDREMONT and G. BANDEL : Reactions during the attack of heat-resisting steels in hot gases.
U. R. EVANS : Corrosion as influenced by increased temperature.
C. H. M. JENKINS : The chemical properties and stability of metals at high temperatures.
C. BENEDICKS : Regarding the factors influencing corrosion at increased temperature.
A. PORTEVIN, E. PRÉTET and H. JOLIVET : Recent progress in and applications of methods of studying corrosion by gases.
S. BRENNERT : Influence of temperature on the formation of pitting in stainless steel.

New Soviet-Russian Investigations in the Field of the Corrosion Protection of Chemical Plant. M. von Pohl. (Korrosion und Metallschutz, 1937, vol. 13, Mar., pp. 97–102). Short summaries are presented of the contents of the undermentioned papers, &c., taken from various Russian sources :

W. D. JACHONTOW : The corrosion of materials in the construction of chemical plant.

P. P. BELJAJEW, J. B. GUREWITCH and J. BIRMAN : The electrolytic lead-plating of chemical plant.

D. I. SYTSCHEW : Acid-resisting silicate linings for reaction vessels.

ANNENKOW : A new acid-resistant coating " Bituminol."

M. I. FARBEROW : Application of rubber in the corrosion protection of chemical plant.

From the Researches of the Federal Conference " Corrosion and the Chemically Resistant Metals " on the attack on metals by phosphoric, silisic, hydrofluoric and similar acids.

K. N. IWANOW and L. J. KOSLOW : The corrosion of special steels in the synthesis of methanol.

L. L. KUSJMIN : The chemical destruction of material by solutions of sulphur and of ammonium sulphate, sulphite and thiosulphate, at high pressures and temperatures.

I. I. SIDOROSCHIN : The attack on metals by boiling liquids under a vacuum.

M. M. ROMANOW and O. I. WER : The corrosion of materials in the manufacture of artificial leather.

E. ANNENKOW : Acid-resistant linings of Textolit and Chaweg.

Deterioration of Structures in Sea-Water. (Department of Scientific and Industrial Research, London, 1937). The Sixteenth (Interim) Report of the Committee of the Institution of Civil Engineers contains a short paper by J. Newton Friend in which an analysis is made of the various commercial galvanised articles used by the Committee in their experiments. It is shown that the galvanised plates were unusually heavily galvanised, a feature which would explain their high resistance to corrosion.

Intergranular Corrosion and Structural Etching of Steel with 18% Cr and 8% Ni. P. Schafmeister. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Mar., pp. 405–413). By the investigation of that part of the steel going into solution during the intergranular corrosion of 18/8 chromium-nickel steel, it was possible to show directly that the intercrystalline decomposition is due to the impoverishment in chromium of the martensite bordering the grain boundaries resulting from carbide precipitation on annealing. The dissolved portion of steels annealed at 600–750° C. contained only 9–13% of chromium; in steels annealed at temperatures above 800° this figure returned to 18%, in agreement with the theoretical value. Iron-chromium carbides separated out of annealed 18/8 steel have a " noble " potential, whereas that of the martensitic border zone is not. Finally, tests were made to see whether the tendency to intergranular corrosion could be recognised by examination of the structure—that is, whether austenite, ferrite, the martensitic border zone and carbides could be distinguished by etching. In

order to reveal the precipitated carbides, electrolytic etching in 10% ammonium nitrate solution is recommended.

Contact Effects of Glass and Platinum on the Dissolution of Iron and Steel in Nitric Acid of Various Concentrations. H. Endô and H. Kawasé. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Dec., pp. 755–770). In a previous paper the authors reported that the part of a specimen of iron in contact with glass was markedly attacked and its shape altered in a concentrated solution such that the iron dissolved periodically. In the present paper this phenomenon has been examined further and the contact effect of platinum has been studied. The change of shape due to contact with glass and platinum was also observed in dilute solutions of nitric acid (less than 45%) when the iron was immersed in them for a long time. But when a small plate of glass was placed in close contact with the surface of an iron sheet, the contact plane retained its original condition. The explanation given is that chemical, physical and mechanical actions are involved in the removal of the liquid film of complex salt, $[Fe(NO)](NO_3)_2$, formed on the surface of the iron dissolving in the acid.

Use of the Thyssen-Bourdouxhe Apparatus for the Determination of Corrosion by Solution. P. Bastien. (Métaux et Corrosion, 1937, vol. 12, Feb., pp. 32–35). The apparatus described is intended for making corrosion tests in a slowly moving liquid medium on small specimens, 65 mm. long by 5 mm. in dia.; it has been used primarily for light metals and alloys, but also for cast iron. The specimen is contained in a horizontal wide-bore tube; the latter is connected at each end to a glass bottle, and the latter in turn are in connection with an inverted conical flask placed above them. The whole system is filled with the corroding solution, an air space being left above the liquid in the inverted flask. A water pump withdraws air from this air space and injects it into one of the tubes leading up to the inverted flask; acting on the principle of the air lift, the bubbles of air, rising in the tube, cause the whole of the liquid in the system to circulate slowly. The corrosion is measured by the loss of weight. The rate of circulation of the liquid has some influence on the rate of corrosion, but a curve shows that, for magnesium in 1% aqueous hydrochloric acid solution the curves for 4·6 and 6·8 m. per min. coincide; the rates of circulation normally used would lie between these limits.

New Researches on the Intercrystalline Corrosion of Ferro-Nickels containing Chromium. P. Chevenard. (Métaux et Corrosion, 1937, vol. 12, Feb., pp. 23–31). The author first gives a short account of the development of the French steel *ATV* used for turbine blades, which contains about 34% of nickel, 11% of chromium and 0·3% of carbon. He next describes methods for determining the chemical heterogeneity of the metal which gives rise to liability to intercrystalline corrosion: (*a*) Observation of the Curie point, which is notably affected by heat treatment, and (*b*) a test in which

specimens are attacked by a mixture of sodium thiosulphate and hydrochloric acid solutions, after which the electrical resistivity, increased by the fissures produced, is measured. In the next section the author presents and discusses the influence of heat treatment (hyperquenching and tempering) on the heterogeneity and carbide precipitation of specimens of *ATV* steel and on the mechanical and chemical properties, and in the last section he deals with the effect of cold-work following hyperquenching and preceding tempering; the results are set out in a number of diagrams. The principal fact emerging from these tests is that a ferro-nickel containing chromium may be rendered liable to intercrystalline corrosion by cold-work following hyperquenching without tempering at all.

Corrosion of Condenser Tubing in a Gulf Coast Oil Refinery. H. M. Wilten. (Mining and Metallurgy, 1937, vol. 18, Mar., pp. 143–147). The author describes the corrosion of shell- and tube-type exchangers and condensers used in petroleum-refining equipment for the condensation of vapours and the cooling of liquids. Deterioration is due primarily to water corrosion, which, on account of the high temperatures used, is much more severe than the water corrosion of this type of equipment used in other industries. The author presents data giving the service life of steel and alloy-steel tubing and comparing it with the service life of Admiralty metal tubing. The failure of 18/8 steel tubes is discussed at length.

The Behaviour of Metallic Materials in the Tanning and Leather Industry. R. Lauffmann. (Korrosion und Metallschutz, 1937, vol. 13, Mar., pp. 81–86). The author presents a summary of a number of researches, carried out by varied workers between 1932 and 1935, on the corrosion of metals in the tanning and leather industries.

Progress in the Corrosion Protection of Refrigerating Plants. E. Belani. (Korrosion und Metallschutz, 1937, vol. 13, Mar., pp. 94–95). A brief summary of the present state of development of the prevention of corrosion in refrigerator plants.

The Effect of Fibre Cores on Internal Corrosion in Colliery Winding Ropes. J. E. O. Mayne. (Mines Department, Safety in Mines Research Board, Paper No. 97). Internal corrosion-fatigue is the most dangerous type of deterioration leading to the failure of colliery winding ropes, and only a small amount of internal corrosion is needed to promote this condition. The author describes an investigation to determine the effect of hemp and other fibre cores on internal corrosion. The following conclusions are drawn from the results. Batching and impregnating oils used in core manufacture do not decompose sufficiently, in practice, to cause appreciable corrosion of wire; on the contrary, they protect it. Darkening of the oils is due to the presence of impurities such as coal dust and iron oxide, and the oils retain their protective value until they are squeezed out. Internal corrosion can take place without penetration of the rope by water containing harmful salts or acids derived from

sources external to the rope. Manilla (and some other) fibres used for cores contain and are liable to develop formic and acetic acids as a result of bacterial action. These acids can corrode wire ropes in the presence of moisture even in the absence of oxygen; pressure between wire and core tends to accelerate the rate of attack, since it tends to remove the protective oils and increase the contact between the fibre and steel. The erratic distribution of corrosion is due to the sporadic nature of bacterial action. It is shown that the harmful acid in raw manilla fibre can be removed by cold water treatment, and it is suggested that subsequent bacterial action might be prevented by treating the washed fibre with an antiseptic which would not corrode steel. The practicability of these measures has, however, not yet been demonstrated.

Soil-Corrosion Studies, 1934. Field Tests of Nonbituminous Coatings for Underground Use. K. H. Logan and S. P. Ewing. (Journal of Research of the National Bureau of Standards, 1937, vol. 18, Mar., pp. 361–388). A series of tests of metallic and other non-bituminous coatings has been carried out by the National Bureau of Standards to determine their suitability for the protection of structures exposed to corrosive soils. Tests of calorised pipe in a few soils indicate that this type of coating affords only partial protection. Lead corrodes sufficiently in many soils to render thin lead coating unsatisfactory. Of the metallic coatings tested zinc was the best. However, zinc coatings gradually deteriorate in many soils. Several new coatings have been under observation for two years. For this period of exposure, the best of these were a vitreous enamel and two rather thick rubber compounds.

Underground Corrosion. K. H. Logan. (Transactions of the American Society of Civil Engineers, 1936, vol. 101, pp. 811–833). The author discusses the characteristics and causes of underground corrosion. The major cause of the corrosion of ferrous pipe materials seems to be non-uniformity in the distribution of oxygen and moisture along the surface of the pipe line. Among the methods suggested for reducing corrosion losses are the use of copper and copper-alloy pipe which corrode less rapidly than ferrous materials, increasing the thickness of the pipe walls and the use of protective coatings.

MINERAL RESOURCES

The Distribution and Properties of British Coals. J. G. King. (Journal of the Society of Glass Technology, 1937, vol. 21, Apr., pp. 196–214). The coalfields of Great Britain contain all the important types of coal, with the exception of lignite, but these can be defined only approximately in terms of the coalfield, since some fields show a wide variety of types. The Fuel Research Survey is steadily compiling data regarding the important seams and also commercial grades. The seam sections are taken by a special technique, and the results of analysis can be graphed over the entire field to show the trend of variations.

The Mining and Supply of Iron Ores in England. F. Friedensburg. (Glückauf, 1937, vol. 73, May 15, pp. 433–442). The author reviews the iron ore resources of England, describing the geology and characters of the various deposits, and the origin and types of ores imported to make up the balance of the iron industry's requirements. In conclusion, he deals briefly with the economic situation.

The Mineral Deposits of Southern Singhbhum and Surrounding Areas. J. A. Dunn. (Memoirs of the Geological Survey of India, 1937, vol. 69, Part I.). The mineralogy and general geology of the mineral deposits of Southern Singhbhum and surrounding areas are described. Particulars are given of the hematite, magnetite, manganese and chromite deposits. Chapter 21 of the Memoir comprises an account of the iron ore mines of the Tata Iron and Steel Co., Ltd., by F. G. Percival.

Geology and Fuel Resources of the Southern Part of the San Juan Basin, New Mexico. Part III. The La Ventana-Chacra Mesa Coalfield. C. H. Dane. (United States Geological Survey, 1936, Bulletin No. 860C). This report describes the geology and coal deposits of an area including about 1000 sq. miles in south-eastern San Juan, north-western Sandoval, and north-eastern McKinley Counties, in north-western New Mexico. The coal is of sub-bituminous rank and of fairly good grade, but the coal-beds are very irregular and lenticular. Most of the coal-beds are thin, but some beds are from 5 to 9 ft. thick.

The Mineral Industry of Alaska in 1935. P. S. Smith. (United States Geological Survey, 1937, Bulletin No. 880A). Developments in the mineral industry of Alaska are reviewed. Statistics are given of the mineral production for 1935 and previous years.

Geology of the Kouyatung Coalfield between Hunan-Kwangtung Provinces. C. C. Tien, H. C. Wang and J. L. Hsu. (Bulletin of the Geological Survey of China, Mar., 1937, No. 29). The geology of this coalfield is described and particulars are given of the composition and character of the coal and the coal reserves.

ORES—MINING AND TREATMENT

Ironstone Working with Mechanical Diggers. (Iron and Coal Trades Review, 1937, vol. 134, Mar. 5, pp. 439–440). Particulars are given of the electrically operated diggers in use at the Stainby Quarry of the Stanton Iron Works Co., Ltd., for the quarrying of ironstone.

Mining Methods at Iron Knob, South Australia. D. G. Dey. (Australasian Institute of Mining and Metallurgy, 1936, No. 103, Sept., pp. 343–384). In setting out the methods and machinery employed at Iron Knob, the author deals with the working methods in use to-day, beginning with drilling, blasting, quarry traction, &c., and touching on such details as the supply of electricity, water and compressed air. The situation, topography and geological features are not dealt with.

Modern Preparation of the Siegerland Ores. H. Gleichmann. (Stahl und Eisen, 1937, vol. 57, Mar. 18, pp. 289–296). After indicating the mineralogical, physical and technical principles underlying the preparation of the Siegerland ores, the author describes the methods adopted for dressing spathic iron ore. The technical and economic aspects of the treatment of raw and roasted spathic ore are dealt with, and the present development of the roasting technique is explained. Operating results are given. The preparation of copper ores and of lead-zinc ores, particularly by flotation, is also described.

Physical Properties of Magnetite and its Possible Uses as an Industrial Mineral. R. S. Dean and C. W. Davis. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 795; Mining Technology, 1937, vol. 1, Mar., No. 2). The authors suggest several possibilities for increasing the use of magnetite as an industrial mineral rather than as a metallurgical raw material. The use of magnetite for the rapid direct measurement of grinding efficiency has already become well established. Other possibilities, the intensive study of which might result in an increased market for magnetite, are its use for cores for certain types of circuits, for permanent magnets, for pigments of paints and for the improvement of magnesite refractories. Another possible use is in the Chance process of mineral separation.

REFRACTORY MATERIALS

(Continued from pp. 1 A–3 A)

The Action of Alkalis on Refractory Materials. Part II. The Action of Potassium Chloride Vapour on Refractory Materials at 1000° C. F. H. Clews, A. Green and A. T. Green. (Transactions of the Ceramic Society, 1937, vol. 36, Apr., No. 4, pp. 217–224). Data are presented in regard to the attack on three types of refractory products of dry potassium chloride vapour at 1000° C. for periods of up to 367 hr. The attack was slight in the case of the silica product, appreciable in the case of the aluminous product, and still more pronounced with the fireclay product. In no case was disintegration or appreciable fluxing of the products observed.

The Action of Alkalis on Refractory Materials. Part III. Volatilisation from Alkali Impregnated Refractory Materials at 1000° C. and 1100° C. F. H. Clews and A. T. Green. (Transactions of the Ceramic Society, 1937, vol. 36, Apr., No. 4, pp. 225–232). The authors present the results of an investigation of the rates of volatilisation of potash and soda at 1100° C. and 1000° C. respectively from various impregnated refractory materials.

Refractories Application—the Trend in the Steel Plant. A. V. Leun. (Iron and Steel Engineer, 1937, vol. 14, Mar., pp. 36–46). The author discusses the improvements which have been made in both the manufacture of refractories and their application to steel-making purposes.

Backing Up Refractories with Insulating Material. G. E. Grimshaw. (Steel, 1937, vol. 100, Apr. 12, pp. 89–94; Apr. 19, pp. 51–59). The author deals with the insulation of back walls and roofs of industrial furnaces and describes the properties of various insulating materials used.

FUEL

(Continued from pp. 4 A–6 A)

Sources of Error in the Determination of the Calorific Value of Fuels. H. H. Müller-Neuglück. (Glückauf, 1937, vol. 73, Apr. 17, pp. 345–355). The precise details for carrying out determinations of the calorific values of fuels are given in German Specification DIN DVM 3716, yet comparative tests on identical fuels made at various laboratories have produced wide variations in the results. The cause of these variations lies in the extreme sensitivity of thermochemical reactions—hence the necessity for the most minute description of all the experimental details and for working as closely to the specification as possible. The author reviews the various ways in which errors may be introduced.

A Steelworks Power Plant in the Sense of a Progressive Energy Management. G. Hubel. (Stahl und Eisen, 1937, vol. 57, May 6, pp. 494–500). A review of developments in power plant turbines, and a comparison of this type of prime mover with the gas engine are presented.

Calculation of Conduits for Fluids, taking Account of Exchanges of Heat (Gas under Pressure, Steam, Hot Gases, Chimneys, Thermosyphon). A Mondiez. (Chaleur et Industrie, 1936, Vol. 17, Sept., pp. 339–348; Oct., pp. 397–404; Nov., pp. 441–448; Dec., pp. 489–497; 1937, vol. 18, Mar., pp. 122–128). The author presents a mathematical consideration of the mechanical, thermodynamic and hydrodynamic aspects of the flow of fluids in pipes and tubes.

Reflection of Heat Radiation at Technical Surfaces. E. Eckert. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Apr. 10, p. 441). In the calculation of heat exchanges in technology it is almost always assumed that the reflected radiation is completely diffused. Experiments, in which the directional distribution of the radiation reflected from various surfaces resulting from nearly vertical incident radiation was measured, showed, however, that this assumption is not true in all cases.

Checker Brick in Open-Hearth Service. W. C. Buell, jun. (Bulletin of the American Ceramic Society, 1937, vol. 16, Apr., pp. 139–143). The most important factor of regenerator design and operation is the horizontal distribution of the incoming fluids. Horizontal fluid distribution is a function of fundamental furnace layout, design, and operation and is but slightly, if at all, affected by checkerwork design. The depositing of the dust in selected locations is of major importance to the continued effective operation of checkerwork. The most carefully conceived checkerwork will be ineffective to a varying and generally considerable degree as long as horizontal distribution and dust elimination are faulty. Given

the best possible conditions of distribution and dust elimination and bearing in mind the usual conditions of operation, it seems probable that checker design may be varied through considerable limits without materially changing the operation results. Large checker flues offer substantial operating advantages. Cleaning and renewal practice has a considerable effect on over-all practice and results. Thus, checker brickwork as such actually plays but a minor rôle in the operation of a regenerator, although it is almost always named as the acute cause of its constitutional ills.

The Influence of Material, Shape and Size of Checker Brick on Heat Transfer in Regenerators. J. D. Keller. (Bulletin of the American Ceramic Society, 1937, vol. 16, Apr., pp. 144–152). The author has studied heat transfer in regenerators, and concludes that little is to be gained by the use of different material for the checker brick, except insofar as the substitution would result in a rougher surface. Large area of heating surface, rather than great weight, is to be desired in a checker. Considerable improvement can be effected only by decreasing the resistance to heat transfer from the brick surfaces to the air. The most promising path of development appears at present to be (*a*) in making the brick shapes such as to increase the turbulence, and (*b*) in improving the dust and slag separation so that smaller flues can be used. One outstanding improvement which could be made is the insulation and sealing of the downtakes and slag pockets in a really effective manner, to reduce the 300° to 400° drop in temperature of the gases which now takes place in most open-hearth furnaces between the ports and the checkers.

The Use of Oil Immersion in the Microscopy of Coal. E. Stach. (Glückauf, 1937, vol. 73, Apr. 10, pp. 330–333). The author explains the advantages of the use of oil-immersion technique in the microscopy of coal and describes its application.

The Friability of South African Coals. J. C. Vogel and F. W. Quass. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 37, Mar., pp. 469–478). The authors have studied the resistance to impact of twenty-five typical South African coals by means of shatter tests, and have determined their friability.

Density of Packing as a Characteristic of Fine Coal. C. Koeppel. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1937, vol. 5, Apr., pp. 53–70 : Glückauf, 1937, vol. 73, Apr. 24, pp. 369–378). Starting from the fact that the volume of voids in heaped materials of similar grain-size composition packed as closely as possible is a constant, irrespective of the specific gravity, limiting cases can be developed by calculation and graphically for the filling of the voids by granular matter. The assumption is made that the diameter ratios in the grain-sizes examined tend towards infinite values. Instead of the heaped weight usually employed to characterise the mode of packing of granular materials,

the apparent volume is used as a non-dimensional figure. In checking experimentally the law governing the filling of the voids the weight after shaking down is used instead of the heaped weight, as it gives finite values for the density of packing. It was found that, in principle, coals follow the law governing the spatial arrangement of ideal—that is, spherical—heaped materials.

The Size Composition of Coals. Mathematical Expression. J. Aubery. (Revue de l'Industrie Minérale, Mémoires, 1937, No. 391, Apr. 1, pp. 178–188). The author discusses the search for an algebraical expression by which the classification curves of a coal may be expressed mathematically based on the proportional-effect formula, the interpretation of the variation of the ash content throughout the size grades, and the factors governing the grading of coals.

New Methods of Computing the Washability of Coals. (Colliery Guardian, 1937, vol. 154, May 21, pp. 955–959; May 28, p. 1009). An English translation is given of an article by K. F. Tromp which appeared in Glückauf, 1937, vol. 73, Feb. 6, pp. 125–131; Feb. 13, pp. 151–156. The author describes in considerable detail a new method of assessing the washability of coal based on what he terms "distribution factor curves." (*See* Journ. I. and S.I., 1937, No. I., p. 253).

Experiments on Apparatus for the Flotation of Coal. R. Vieux. (Revue de l'Industrie Minérale, Mémoires, 1937, No. 393, May 1, pp. 227–231). A short account is given of the test results obtained in an investigation of two flotation methods for coal, namely, the "Minerals Separation" and the "P.I.C." Two coals from the North of France were used in the tests; the processes themselves are not described.

New Works of the Barnsley District Coking Co., Ltd. (Iron and Coal Trades Review, 1937, vol. 134, Apr. 2, pp. 613–618). A complete illustrated description is given of the Becker coke-ovens and by-product recovery plant installed at the works of the above-mentioned Company.

The Sheffield Laboratory Coking Test. C. E. Spooner and R. A. Mott. (Fuel in Science and Practice, 1937, vol. 16, Apr., pp. 96–106). The authors describe the uses to which the Sheffield Laboratory Coking Test can be put. They include (1) the effect of storage on coking properties of coal; (2) the effect of adding pitch on the swelling power of coal; (3) the determination of the amount of durain in any grade of coking coal.

Investigations on the Improvement of the Quality of the Coke from Low-Gas, Difficultly-Melted Coals. W. Herrmann and K. Brüggemann. (Technische Mitteilungen Krupp, 1937, vol. 5, Apr., pp. 50–58). In the coking of low-gas fat coals and of admixtures with small proportions of semi-bituminous coal partial variations in the coke quality occurred, which made themselves apparent as middle layers in the coke lumps which had not completely melted. By temperature measurements across the entire

cross-section of the coal charge in a coke-oven the occurrence of a zone of incomplete fusion could be followed, and this was attributed to a low rate of coking. Laboratory tests showed that the coke quality could be considerably influenced by changes in the rate of coking, bulk density, moisture content and size of the charge coal. By the addition of gas-rich fat coals, the proportion of semi-bituminous coal can be increased very much whilst still producing coke of adequate quality. The laboratory results were confirmed by box coking tests in practical operation. Finally large-scale tests produced excellent coke with a 10% admixture of semi-bituminous coal to a low-gas fat coal. According to the experimental results, by adhering to the most suitable coking conditions perfectly good coke can be made from mixtures of low-gas fat coals with 10% of semi-bituminous coal or of gas-rich fat coals with 20–40% of semi-bituminous coal.

Low-Temperature Carbonisation and Combustion. D. E. Brownlie. (Steam Engineer, 1937, vol. 6, Apr., pp. 279–281). A review of developments in Germany in the low-temperature carbonisation of fuel.

The Geller Low-Temperature Coking Process. (Iron and Coal Trades Review, 1937, vol. 134, May 14, p. 890). The general arrangement of the Geller low-temperature coking retort is shown, and particulars are given of operating results.

Phenolic and Other Constituents of Aqueous Liquor from Coal Carbonisation. G. T. Morgan and A. E. J. Pettet. (Journal of the Society of Chemical Industry, 1937, vol. 56, Apr., pp. 109T–113T). The authors deal with the extraction of phenolic compounds and non-phenolic constituents from the aqueous liquors which accompany coal tar.

Oil and Pitch Yields in Working Up Tar. E. Moehrle. (Glückauf, 1937, vol. 73, Apr. 3, pp. 302–306). The author discusses the influence of the operating conditions (distillation pressure, heating period, injection temperature) on the oil and pitch yield obtained in the continuous distillation of coke-oven tar; experimental results are presented. The advantages of continuous distillation are indicated. The treatment of tar by extraction with various solvents is also discussed, and three processes are described.

Testing and Judging of Benzol Wash Oils. E. König. (Glückauf, 1937, vol. 73, Apr. 10, pp. 325–330). The author describes a method of determining directly the ability of a wash oil to absorb benzol further, in which the partial pressure of the benzol in the benzol/wash-oil mixture is measured with the aid of a gas interferometer.

Gas Cleaning Problems. P. A. Abernethy. (Journal of the West of Scotland Iron and Steel Institute, 1936, vol. 44, Dec., pp. 39–52). An illustrated description is given of the Elga electrostatic gas cleaning plant in operation at the Clyde Iron Works, and a brief summary is given of the principles of electrical precipitation.

Designing of Gas-Cleaning Installations. C. W. Hedberg. (Industrial and Engineering Chemistry, 1937, vol. 29, Apr., pp. 406–413). The author discusses a number of factors to be considered in the selection and operation of gas-cleaning equipment.

Producer-Gas for Heating Coke-Ovens. (Institution of Mining Engineers. Utilisation of Coal Committee, Memorandum No. 2, 1937). At gasworks, the retorts are invariably heated by producer-gas made from a proportion of the coke discharged from the retort. In the coke-oven installations which have been erected at gas works, producer-gas has also been used for heating the ovens, as at the Beckton plant of the Gas Light and Coke Co., Ltd. The first examples of the use of producer-gas in this country for heating ovens where by-product coke is the primary product are at Blackwell, Derbyshire, where one gas-producer was installed in 1935 to heat a proportion of the ovens with producer-gas made from coke, and at Orgreave, Yorkshire, where sufficient gas-producers have been installed to heat with producer-gas the whole of a battery carbonising 800 tons of coal per day, the coke-oven gas being piped to the steelworks of the United Steel Cos., Ltd., at Templeborough. An extension of the use of producer-gas for heating coke-ovens must depend mainly on its cost relative to the value which can be attached to the coke-oven gas. The coke-oven gas used at the Templeborough steelworks of the United Steel Cos., Ltd., has led to an increased thermal efficiency of at least 25% over previous practice, most of the gas being used in reheating furnaces, but some, mixed with producer-gas, being supplied to open-hearth steel-melting furnaces (Koopman, Journal of the Institute of Fuel, 1934, vol. 7, p. 245). Even if, as is usually considered, the price per therm of coke-oven gas and producer-gas is about the same, the higher efficiency in use of coke-oven gas makes it at least 25% more valuable. Coke has an essential quality, an absence of swelling on heating, required for a good producer fuel, but since it is usually desired to use a small grade of material the resistance to the blast may be high. The coke should consist mostly of material of $1\frac{1}{2}$–$\frac{1}{4}$ in. size. For a coke-oven plant carbonising 500 tons of coal per day the coke required for the producer would be about 63 tons per day, calculated dry, or about 18% of the total production of coke. It is clear that when all available surplus coke-oven gas is sold and there is a market for more at 1·06d. per therm, it should be profitable to install at least one gas-producer to use the coke breeze available together with coke nuts, provided that the coke is valued at 15s. and the breeze at 5s. per ton. When coke is valued at 20s. and breeze at 10s. per ton, it is uneconomic to heat coke-ovens by producer-gas. It may be noted, however, that, apart from the use of the gas for heating the ovens, a gas-producer can prove a useful adjunct to a coke-oven plant, for the gas, of about 130 B.Th.U. per cu. ft., can be used to dilute coke-oven gas which is of too high a calorific value for delivery under contract.

PRODUCTION OF IRON

(Continued from pp. 7 A–10 A)

The Brosius Electric Blast-Furnace Tap-Hole Stopping Machine. (Engineering, 1937, vol. 143, Apr. 16, p. 431). Brief particulars are given of the design and operation of the Brosius electric clay gun for blast-furnaces.

Operation of a Blast-Furnace to Suit its Lines. J. Stoecker. (Stahl und Eisen, 1937, vol. 57, May 13, pp. 545–552; May 20, pp. 581–584). During the charging of a blast furnace it often happens that the burden becomes " unmixed " into fine and coarse particles, as a result of which denser and more porous zones are formed. The positions occupied by these various zones depend on the lines of the furnace. There is no generally applicable profile for a blast-furnace; during the campaign, indeed, it undergoes changes. Therefore it must be continuously watched, and controlled by suitable means so as to obtain the optimum passage of the furnace gases; in this way maximum efficiency is attained. For satisfactory control of the gas flow, the essential requisites are suitable distribution for the upper part of the furnace and correct types of tuyeres for the lower part. Experiments with a special type of tuyere, developed at the Bochumer Verein, showed very clearly the changes in the gas flow in the lower part of the furnaces due to variations in the use of the tuyere. The enlargement of the oxidation zone produced did not reduce the efficiency of the furnace. This special type of tuyere and its various arrangements are not usable everywhere, but they provide a convenient means of directing the gas flow to one side or the other. By the results described the author indicates ways and means of obtaining at all times a picture of the condition of the furnace; he indicates measures to be taken which, correctly applied, lead to maximum efficiency in the operation of the furnace.

Smelting of Pig Iron Suitable for the Bessemer Process from Krivoj Rog Ores. A. Svitzin. (Stal, 1936, No. 8, pp. 1–6). The author describes in detail the design and operation of two blast-furnaces at Ordzhorikidze Works for the production of Bessemer pig iron from iron ore from the Krivoj Rog district. (In Russian).

The Use of Agglomerate for the Blast Furnaces at Makeevka. K. Messerle. (Metallurgist, Russia, 1936, No. 1, pp. 28–35). The author presents data showing the improvement effected in the operation of two blast-furnaces in Makeevka by using an ore charge consisting of 48% of agglomerate, 8% of graded ore and 44% of ungraded ore. (In Russian).

Some Investigations on the Deposition of Carbon During the Reduction of Iron Ores. B. Kalling and J. Stålhed. (Jernkontorets Annaler, 1937, vol. 121, No. 1, pp. 30–43). An apparatus used for

the study of the successive reduction of iron ore is described. The apparatus was designed with the special object of making possible a detailed study of the carbon deposition during reduction with a gas containing CO. The following results were obtained : Magnetite and wüstite have no appreciable catalytic influence on the carbon deposition, at least not at ordinary pressure. Neither has pure carbon in the form of sugar carbon. Under the conditions prevailing in the blast furnace metallic iron is with certainty the only substance which can be of any importance as a catalyst. It was confirmed that carbon deposition does not considerably influence the fuel economy of the blast-furnace even if easily reducible sinter is used. On passing CO over metallic iron, the iron lost in weight, while a corresponding content of iron was found in the deposited carbon. This indicates that the iron takes an active part in the carbon deposition reaction.

Reduction of Iron Oxides by Carbon Monoxide and by Solid Carbon. N. Kostylev. (Metallurgist, Russia, 1936, No. 1, pp. 7–28). The author first discusses the reactions in the blast-furnace, under ideal conditions of equilibrium, of the three systems : FeO–O-gas; Fe_3O_4–FeO–gas; Carbon–gas. The reaction which occurs according to the equation $9Fe_2O_3 + 43CO \longrightarrow 18Fe + 27CO_2 + 16CO$, requires 0·474 kg.-cal. The author compares this ideal case with the reactions taking place under actual conditions, including the formation and dissociation of Fe_3C, and Bell's reaction ($2CO \longrightarrow CO_2 + C$). With well-prepared ores, the whole of the Fe_3O_4 and about one half of the FeO are reduced, at temperatures up to 800° C. and 950° C. respectively, either by CO, or by carbon from Bell's reaction—*i.e.* ultimately also by CO (" indirect reduction "). Only the remaining half of the FeO is reduced by coke (" direct reduction "). (In Russian).

Planned Materials Economy in Ironworks. E. A. Matejka. (Stahl und Eisen, 1937, vol. 57, Apr. 1, pp. 341–348). The author discusses the relationship of materials economy in an iron and steel works to operating economy, and the field covered by materials economy. He describes the organisation and mode of working of a materials-economy department, and gives examples in illustration.

FOUNDRY PRACTICE

(Continued from pp. 11 A–12 A)

Cupola Practice. W. Spiers. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 22, pp. 327–328). A brief discussion of the operation of cupolas.

Electric Furnace Cast Iron. C. H. Morken. (Iron Age, 1937, vol. 139, Apr. 29, pp. 36–41; May 6, pp. 46–49, 120). The author gives particulars of three types of electric furnaces used for the melting of cast iron and points out their relative operating advantages. Electric furnace cast iron is compared with that obtained in fuel-fired furnaces, and the physical properties of electric furnace cast iron are described. The production of wear-, heat-, and corrosion-resistant irons is reviewed.

Alloying Cupola Grey Cast Iron. F. E. Fisher. (Iron Age, 1937, vol. 139, Apr. 29, pp. 43–45, 123). The author lists the various alloying elements usually added to cast iron and summarises their effect on the properties of the iron. A table is given showing the amount of alloying material required for each 100 lb. of metal. Compositions are also given of grey iron castings for various applications.

Bibliography on Synthetic Moulding Sands. G. R. Woodward. (Bulletin of the British Cast Iron Research Association, 1937, vol. 4, Apr., pp. 461–464). This bibliography contains forty-five references and covers the period 1918 to 1937.

Bibliography on the Properties and Uses of Bentonite. G. R. Woodward. (Bulletin of the British Cast Iron Research Association, 1937, vol. 4, Apr., pp. 465–466). This bibliography contains twenty-five references and covers the period 1920 to 1936.

Runners and Risers for Grey-Iron Castings. J. Longden. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 1, pp. 269–273). The author points out a number of factors influencing the arrangement of runners and risers for grey-iron castings, and illustrates the correct positioning of runners and risers for different castings to obtain quick distribution of the metal throughout the mould.

Gates and Risers for Steel Castings. A. D. Kirby. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 15, pp. 311–312). The author points out the advantages of the method of top running for certain types of steel castings, which has been found superior to the generally adopted method of gating at the lowest part of the casting, or in some cases at the joint of the mould.

Practical Notes for Moulders. J. Pattison. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 8, pp. 291–292). The author discusses briefly mould ramming, the position of runners, the venting of moulds, mould finishing and core prints.

Oil Sand Cores and their Testing. H. Nipper. (International Foundry Congress, Düsseldorf, 1936: Foundry Trade Journal, 1937, vol. 56, May 6, pp. 368–369, 370; May 13, pp. 386–397). The author presents a short review of the available literature on oil cores and discusses methods of testing and investigation. He deals with practical works control of oil cores and describes some recent experimental results.

Results of Industrial Scientific Investigations in Loam Moulding Shops and their Reflection in Works Management. C. Bäume. (Giesserei, 1937, vol. 24, May 7, pp. 238–250). The author describes an industrial investigation on the basis of the results of which generally applicable principles for determining piece times in the loam moulding shop are developed. The loam moulding shop was selected as a typical example of a unit production plant.

The Manufacture of Iron and Steel Castings in Green Sand. C. J. Dadswell, T. R. Walker and F. Whitehouse. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 22, pp. 329–333). The authors point out the advantages and disadvantages of green-sand moulding, and outline moulding practice, the use of green-sand cores, the properties of steel in relation to green sand, sand control, the production of synthetic sands, and the form and construction of core irons. Small castings suitable for repetition work lend themselves particularly well to green-sand production. Examples are castings for locomotive construction, carriages and wagons, colliery work, and castings for motor-cars and lorries.

Wasters—Their Cause and Cure. (Iron and Steel Industry, 1937, vol. 10, Apr., pp. 335–339; May, pp. 375–378). A review is given of the causes of wasters in foundry practice, chiefly those due to design and pattern-making, and the means of eliminating waster castings are discussed.

The Manufacture of Valve-Seat Inserts for Ford Engines. E. F. Cone. (Metals and Alloys, 1937, vol. 8, Apr., pp. 89–91). For the production of automobile valve-seat inserts at the plant of the Ford Motor Company, high-speed steel scrap is used. This is melted in an acid electric arc furnace. The metal is poured in green-sand moulds, thirty-six insets being moulded in one plate or slab. The steel used has the following composition: Carbon 1·20 to 1·40; manganese 0·30 to 0·50; chromium 2·50 to 3·50; silicon 0·30 to 0·60; copper 1·50 to 2·00; tungsten 14·00 to 17·00%. The copper is added as scrap copper to the charge.

PRODUCTION OF STEEL

(Continued from pp. 13 A–15 A)

The Basic Open-Hearth Process. H. I. Geiger. (Steel, 1937, vol. 100, Mar. 29, pp. 38–41, 80–82; Apr. 5, pp. 39–44; Apr. 12, pp. 64–68; Apr. 26, pp. 48–52, 78–81). A series of articles in which the author deals with the origin, early history and present-day development of basic open-hearth practice. The constructional arrangement of a modern open-hearth furnace is shown and the making of a heat of basic steel is described. A complete log of a basic open-hearth heat is included and the reactions are described.

The Warming Up of Open-Hearth Furnaces. A. E. Dodd. (Iron and Steel Industry, 1937, vol. 10, May, pp. 372–374). The author deals with the different methods of warming up steel furnaces, showing that coal fires inside the furnace can, with due care, raise the temperature of the brickwork at a fairly uniform rate to 500–600° C., while gas flares can raise the brickwork to 700–800° C., or even higher with small furnaces. It is also shown that the spalling of silica bricks occurs at temperatures well below a red heat, so that with proper control either method of heating is capable of taking a furnace to the gassing temperature without risk of spalling, but since the spalling occurs at such low temperatures—before any heat can be "seen"—pyrometic control is essential.

Production of High-Quality, Commercially Pure Alloyed Ingot Iron. M. Hershhorn. (Stal, 1936, No. 8, pp. 10–21). The author has investigated the production of commercially pure alloyed iron of the "toncan" type (Armco-iron alloyed with 0·4–0·5% of copper and 0·05–0·07% of molybdenum). He discusses in detail the elimination of different impurities. For obtaining a metal with a low carbon content, the final slags must contain 26–36% of ($FeO + 1{\cdot}35\ Fe_2O_3$). The manganese content can be reduced below 0·02% by oxidising as much of the manganese as possible below 1527° C. and twice separating the slags from the metal. The removal of sulphur is difficult; sulphur-free material and fuel must be used. He also describes an experimental heat carried out at the Voroshilovgrad Works, using a mixture of cast iron, sheet-iron scrap and iron ore, with additions of limestone, copper and ferro-molybdenum. The metal was deoxidised by ferrosilicon and aluminium. The product contained 0·1% of molybdenum and 0·24% of copper. The quantity of non-metallic inclusions was very small (0·068% as determined by the chlorine method). The grain size was small. The notch toughness was 45 kg.m. per sq. cm. (20 kg.m. per sq. cm. after ageing at 300–400°). Rolling experiments (to ascertain the possibility of brittleness in the tem-

perature range 800–1000° C.) were inconclusive, on account of the high casting temperature used. (In Russian).

Production of an Experimental Lot of Manganese Sheet Steel. J. Brainin and F. Grigorier. (Stal, 1936, No. 8, pp. 22–31). The authors describe the results of eleven trial heats of manganese steel for shipbuilding, made in the Stalino Metallurgical Works, and make a number of suggestions concerning further production. (In Russian).

Residual Metals in Open-Hearth Steel. J. D. Sullivan and R. A. Witchey. (Metals and Alloys, 1937, vol. 8, Apr., pp. 99–100). The authors have collected data from twenty-one steel companies in the United States and Canada representing an annual tonnage capacity of approximately 8,450,000 tons. Graphs are presented showing the composition of the plain carbon steel base used in the various plants before adjustment of the composition by alloying elements. The information given refers to the year 1936.

Studies on the Acid Open-Hearth Process. B. Kalling and N. Rudberg. (Jernkontorets Annaler, 1937, vol. 121, No. 3, pp. 93–142). The influence of different factors on the composition of the steel before the final additions of silicon and manganese were made was studied in a number of open-hearth heats, worked with different velocities of decarburisation and with different slag compositions. Special attention was given to the connection between the oxygen content and the working of the heat. At higher contents of carbon the oxygen content of the steel was always found to be very low before the additions were made and often even lower than the normal oxygen content in the finished steel. The content of undissolved oxide particles was also found to be very low. This seems to indicate that the method of finishing the heat as well as the tapping and pouring conditions are the factors chiefly responsible for the slag content of the steel. A study of the last-mentioned factors is at present in progress. It seems possible that the method of working the heat has an influence on the steel quality mainly in an indirect way, the composition and properties of the furnace slag effecting changes in the composition of the steel after adding the deoxidisers and during tapping and pouring. A high velocity of decarburisation does not cause an increased oxygen content in the steel as long as the carbon content is high. A vigorous boiling should thus be maintained during the first part of the heat by means of sufficient ore additions. In this way the time of the heat is lowered and the reduction of silicon is facilitated. Towards the end of the heat the rate of decarburisation should be decreased in order that the slag may become sufficiently viscous not to react too vigorously when the additions are made and during tapping. The higher the reduced silicon content, the easier it is to obtain a viscous slag. The different factors determining the composition of the furnace slag, and especially the FeO content, are discussed. By increasing the manganese content or adding lime,

the FeO content may be considerably lowered without any detrimental effect on the decarburising action of the slag. The reactions between slag, steel and furnace lining could in all cases be brought into good agreement with the equilibrium diagram by Körber and Oelsen for slags saturated with silica. The silicon reduced was found to originate from the lining, while oxidation of silicon occurred at the boundary surface between the steel and slag.

Heat Evolutions of Metallurgical Reactions. II. H. Ulich, C. Schwarz and K. Cruse. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 493–500). In an earlier paper published by Schwarz in 1932 a number of data for the heats of various reactions were published; since then the methods of determination have been improved and knowledge of the reactions themselves has advanced, and in the present paper the latest values are tabulated in great detail. The reactions involved are those concerned in (1) combinations of carbon with oxygen, hydrogen and nitrogen, (2) compounds of hydrogen, (3) oxides, (4) carbides, (5) nitrides, (6) halides, (7) sulphides, (8) phosphides, (9) silicides, (10) cyanides and carbonyls, (11) intermetallic compounds, (12) carbonates and hydroxides, (13) phosphates, (14) silicates and aluminates, and (15) slags; in all, 204 reactions are listed.

Investigation of the System TiO_2–SiO_2. D. Bogatzky. (Metallurgist, Russia, 1936, No. 1, pp. 59–67). The author has investigated the TiO_2–SiO_2 system, and uses the results to determine the composition of a silico-titanium which, when used as a deoxidiser in steel manufacture will produce slags of the lowest melting point. (In Russian).

Examples of the Calculation of Economic Efficiency. Part III. H. Euler and H. Diercks. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 525–539). The authors present four more examples of the calculation of the economic efficiency of a plant or process (*see* Journ. I. and S.I., 1937, No. I., p. 159 A). The cases considered are the following: (*a*) Valuation of various kinds of scrap for the pig-and-scrap process and determination of the total cost of production in reichsmarks per ton of sound ingots; (*b*) valuation of cokes with various ash and moisture contents; (*c*) determination of the permissible cost of fuel for a boiler plant; and (*d*) the choice between home-production of gas or its obtainment from an outside source.

Basic Open-Hearth Slag an Important By-Product at the Ensley Works. R. L. Bowron. (Mining and Metallurgy, 1937, vol. 18, Apr., pp. 198–199). At the Ensley Works of the Tennessee Coal, Iron and Railroad Company, pig iron containing more than 0·04% of phosphorus is first blown in an acid converter and separated as completely as possible from the silicious slag. The phosphorus in the blown metal, owing to the loss of the carbon, silicon, manganese and some iron, is increased from 0·83 to 0·90%. This metal is given a washing action by pouring it into a basic open-hearth

furnace through a layer of molten slag. The slag is then immediately poured over the fore-plate of the furnace into slag boxes. Ten tons of slag are produced per heat of 110 tons, of which 8 tons are available, the balance being lost as spillage, or is contaminated, making it unfit for a marketable product. The slag contains 14·54% of phosphoric acid, of which 11·53% is soluble in citric acid. Immediately the slag has cooled it is transferred to a soil-conditioning plant and mixed with a slag of lower phosphoric acid content. It is then broken up and crushed to a fineness of 90% through 100 mesh. The final product is marketed with a phosphoric acid content of from 8 to 12% and a fineness of 80% through a 100-mesh screen.

Some Factors Influencing Segregation and Solidification in Steel Ingots. L. H. Nelson. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 802; Metals Technology, 1937, Apr., No. 3). The author discusses the following factors which affect the segregation and solidification of killed hot-top steel ingots: (1) Pouring temperature, (2) volume in the hot top, (3) taper in the ingot, (4) pouring rate by varying the nozzle size, (5) segregation of several elements, (6) moving ingots before complete solidification. In most of the discussion, segregation is measured in terms of the carbon variation only. The data presented lead to the following observations concerning the segregation in killed S.A.E. 1040 ingots, 20 in. square: Normal pouring temperatures are best to avoid excessive segregation. The volume of metal in the hot top must be correct to keep segregation at a minimum. Volumes that are too small give segregation and pipe; volumes that are too large result in a waste of steel. The segregation may be influenced by the taper in the mould. The rate of pouring the ingot (with the limits referred to) does not affect segregation, but excessively fast or slow pouring probably has an influence. It is important that killed ingots should not be moved before they are completely solidified. In conclusion, the author suggests that in determining ways of preventing excessive positive segregation at the top of an ingot the investigator should not neglect to test the segregation and soundness lower down in the ingot. It is the author's experience that some procedures that reduce positive segregation at the top of the ingots may also increase negative segregation and unsoundness along the central axis near the middle of the ingot.

Dendritic and Non-Dendritic Primary Structure in Ordinary Mild Steels. J. Seigle. (Chimie et Industrie, 1937, vol. 37, Apr., pp. 629–635). Using a small ingot and several runners of slightly pearlitic basic open-hearth mild steel, the author carried out an investigation of the occurrence of both a dendritic and a non-dendritic primary structure in the metal. He found that the dendritic structure formed in regions which cooled slowly, whereas the non-dendritic structure occurred where cooling had been more rapid; both structures could occur simultaneously in the same ingot.

REHEATING FURNACES

High-Output Pusher Furnaces. A. Sprenger. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Mar. 20, pp. 357–359). The output of pusher furnaces is considerably increased by the use of raised water-cooled skids on which the ingots pass through the furnace. The author describes several types of such raised skids and the mode of water-cooling, and shows the economy of the system by reference to the heat consumption.

Important Advantages Derived from Improved Soaking-Pits. A. L. Hollinger. (Steel, 1937, vol. 100, Mar. 22, pp. 41–42). Brief particulars are given of the one-way fired soaking-pit which is fitted with a cover having a sand seal and provided with automatic combustion and temperature control. The air for combustion is preheated in recuperators.

Side-Door Heating Furnaces. M. J. Conway. (Iron Age, 1937, vol. 139, Apr. 15, pp. 34–39). The author describes the recuperative side-door heating furnace with controlled atmosphere and pressure in operation at the plant of the Lukens Steel Co.

Furnace Pressure and Temperature Control for Side-Door Heating Furnaces. M. J. Conway. (Iron and Steel Engineer, 1937, vol. 14, Apr., pp. 30–34). The author describes and illustrates the design and methods of control of a recuperative side-door heating furnace in operation at the plant of the Lukens Steel Co., Coatesville, Pa. He presents operating results, and compares them with those obtained with the conventional regenerative furnaces in operation at the same plant.

Continuous Furnaces for Reheating Steel for Rolling or Forging. L. Bovet. (Arts et Métiers, 1937, vol. 91, Mar., pp. 56–64; Apr., pp. 93–95). A general discussion of steel reheating furnaces of the continuous type; attention is given to the following aspects: Efficiency, and heat losses by radiation, convection and conduction, and through the chimney; heat consumption; the temperature of the waste gases and of the charge; recuperators; and dimensions of the furnace. In conclusion, an example is given in illustration.

FORGING, STAMPING AND DRAWING

(Continued from p. 16A)

Design of Drop Forging Dies. G. A. Smart. (Heat Treating and Forging, 1937, vol. 23, Mar., pp. 118–121). The conclusion of a series of articles in which the author discusses a number of problems in the design of drop forging dies. (*See* p. 16).

Drop Hammer Design and Construction. M. S. Reed. (Drop Forging Association, Feb. 11, 1937: Heat Treating and Forging, 1937, vol. 23, Mar., pp. 122–126). Developments in the design and construction of drop forging hammers are briefly reviewed.

The Greenbat Hot Forging Machine. (Iron and Coal Trades Review, 1937, vol. 134, Apr. 9, pp. 654–655). The Greenbat horizontal upsetting type of hot forging machine is described and illustrated.

Cold Pressing Alloy Steels. R. Saxton. (Wire and Wire Products, 1937, vol. 12, Apr., pp. 195–200). The author outlines British practice for the cold-drawing of alloy and stainless steels, with particular reference to heat treating.

Republic's Wire Mill Discloses Advancement in Practice. (Steel, 1937, vol. 100, May 3, pp. 42–45, 94). Illustrated particulars are given of the wire mills of the Republic Steel Corporation, South Chicago, Illinois. The wire-drawing equipment consists of three continuous machines for 4-, 5-, or 6-draft wire; four continuous machines for 3-draft wire and four double-decked machines for 1- and 2-draft wire. These machines are designed for high speed, with variable-speed, 230-v. D.C. motors, and full magnetic dynamic breaking control on each block. Particulars are also included of the electro-galvanising plant.

Some Practical Notes on "Casting" Wire. W. Gould. (Wire and Wire Products, 1937, vol. 12, Apr., pp. 177–181). The author describes the work of A. S. Kenneford and F. C. Thompson on the "casting" of wire which was reported in Carnegie Scholarship Memoirs, 1933, vol. 22, p. 31. He also describes his own experiments.

ROLLING-MILL PRACTICE

(Continued from pp. 17 A–18 A)

Spread during Rolling. E. Siebel. (Stahl und Eisen, 1937, vol. 57, Apr. 22, pp. 413–419). The author shows that, by using the laws of flow applicable to the plastic state, and starting out from the resistances in the longitudinal and transverse directions offered to the flow of the displaced material, the spread of the metal occurring during rolling can be calculated for rectangular sections. The influence of the dimensions of the material and of the reduction in the pass are shown. Generally the influence of the friction between roll and material is slight, because as the rolling friction alters there is a corresponding change in the resistance to flow in both the longitudinal and transverse directions, and the effects partially cancel out. The author discusses various formulæ that have been proposed for calculating the spread in rolling.

Phenomena during the Hot-Rolling of Medium-Hard Carbon Steels. W. Lueg. (Stahl und Eisen, 1937, vol. 57, Apr. 1, pp. 349–354). Extract from a paper by A. Pomp and W. Lueg in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1936, vol. 18, No. 13, pp. 183–204.

Hot-Rolling Tests on Carbon and High-Alloy Steels under Various Rolling Conditions. A. Pomp and G. Weddige. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 5, pp. 65–86). Earlier investigations of the influence of the composition of the steel on its behaviour during hot-rolling had been restricted to plain carbon steels or to certain rolling conditions, *e.g.*, ingot rolling; the wider problem of the influence of the composition had not been considered, and so the present experiments on carbon and high-alloy steels, rolled at various temperatures and with various drafts, were undertaken. The steels used comprised a low- and a high-carbon plain steel, a scale-resisting ferritic silicon-chromium-aluminium steel, a rustless austenitic chromium-nickel steel, a non-scaling austenitic chromium-nickel steel and a heat-resistant carbide-rich austenitic chromium-nickel-tungsten steel; they were rolled at 685°, 875°, 1020° and 1185° C., with reductions of 10, 20, 30 and 40%. In the carbon steels, raising the carbon content increased the average resistance to deformation and the moment of rotation only up to rolling temperatures of about 900° C.; above this temperature the resistance of the high-carbon steel was less than that of the low-carbon steel. The high-alloy ferritic silicon-chromium-aluminium steel behaved similarly. The resistance of the high-alloy austenitic and the carbide-rich steels was several times greater than that of the

carbon steels, even at the highest temperatures. The speed gain decreased with rising temperature, only slightly for the carbon steels but very much for the high-alloy steels. The spread appeared to be independent of both the composition and the temperature. All the steels developed the finest microstructure during rolling at 875° C., the exception being the high-carbon plain steel, in which rolling at 685° produced the best structure. Even at the highest temperatures the high-alloy steels showed elongation of the structure; here the coarsening of the grain was very marked. Experiments with different rates of rolling gave unsatisfactory results, as, owing to the heavy cooling at low speeds, comparable rolling temperatures could not be obtained. The relation between the roll pressure and the power required was shown by means of measurements of the moment of rotation.

Automatic Control in the Rolling Mill. E. Aristov. (Stal, 1936, No. 8, pp. 42–55). The author reviews the methods for the automatic control of the rolling pressure, of the velocity, thickness and length of the rolled strip, of its cross-section, of the weight and size of the pieces after rolling, &c. (In Russian).

Roll Bearings of Wood and Artificial Resin. H. Cramer. (Stahl und Eisen, 1937, vol. 57, Apr. 29, pp. 437–441). The author describes and illustrates wooden and artificial-resin bearings for rolling mills which have given satisfactory results in use.

Experiences with Artificial-Resin Pressed-Material Bearing in Rolling-Mills. A. Schiffers. (Stahl und Eisen, 1937, vol. 57, May 6, pp. 500–507). The author describes the steps taken in introducing artificial-resin compressed-material bearings for the various rolling-mills of the Neunkirchner Eisenwerk, Germany. The standardisation of parts, the design of the bearings and roll necks, structural alterations to the mill housings, the water-cooling system for the bearings, &c., are dealt with in detail. Operating results and the economy of the bearings, and also the cooling water and maintenance required are discussed. Finally the author draws certain conclusions applicable to other types of rolling-mills. The mills converted to the new type of bearing comprised two ingot mills, a billet mill, two heavy finishing-mills, nine intermediate mills and six light finishing-mills.

Efficient Method of Removing Scale from Under Blooming Mills. A. Alexandrov. (Stal, 1936, No. 8, pp. 56–63). The author describes the "dry" and "wet" methods of scale removal from under rolling mills. He emphasises the advantages of the hydraulic method. (In Russian).

New Two-High Reversing Universal Rolling Mill. R. Heifer. (Stahl und Eisen, 1937, vol. 57, Apr. 15, pp. 398–400). An illustrated description is given of a two-high reversing universal mill built recently by the Fried. Krupp Grusonwerk A.G. The plant is designed for an annual output of 140,000 tons, but this can be raised to 200,000 tons. Slabs measuring 100–200 mm. thick by 300–

1000 mm. wide will be rolled down to plates 6–50 mm. thick and 300–1100 mm. wide. The horizontal rolls are 780 mm. in dia., with a body length of 1200 mm., and the vertical rolls are 600 mm. in dia.

The Rail Mill of the Magnitogorsk Works. M. Saroschensky. (Stal, 1936, No. 8, pp. 32–41). A description is given of the design adopted for the construction of a rail mill with a yearly output of 1,620,000 tons. (In Russian).

Shot Blasted Cold Rolls Impart Dull Finish to Sheets. (Steel, 1937, vol. 100, May 3, pp. 82–85). At the plant of the Weirton Steel Co., Weirton, West Virginia, the rolls used in the production of cold-rolled sheets are roughened by means of shot blasting. This roughening of the roll surface produces a dull type of finish on the sheet which is said to be an advantage in the subsequent drawing operations, by making possible a tighter gripping of the dies and thus preventing slippage. The shot blasting equipment is described.

Bethlehem's Continuous Strip Mill. (Iron and Steel Engineer, 1937, vol. 14, Apr. Supplement). A complete illustrated description is given of the continuous strip mill at the Lackawanna plant of the Bethlehem Steel Company, which has a nominal annual capacity of 600,000 tons.

HEAT TREATMENT

(Continued from pp. 19A–20A)

Diffusion of Elements in Solid Iron. D. Proshkin. (Metallurgist, Russia, 1936, No. 1, pp. 35–45). The author has investigated the diffusion of elements in iron in the following two ranges of temperature : (*a*) In the region where the diffusing element gives an uninterrupted series of solid solutions with iron, and (*b*) in the region where the increase in concentration of the diffusing element causes a phase transformation. In case (*a*), the polyhedral structure of the crystallites remains unaffected by diffusion; in case (*b*) a new structure appears after the original phase has become saturated. The new crystallites are elongated in shape with their axis in the direction of diffusion. (In Russian).

Equilibria in the Carburising of Iron by Gases. O. Madono. (Bulletin of the Institute of Physical and Chemical Research, 1937, vol. 16, No. 5, pp. 258–264). (In Japanese).

Contribution on the Mechanism of the Scaling of Iron. W. Baukloh and J. Sittard. (Metallwirtschaft, 1937, vol. 16, Apr. 2, pp. 323–325). The authors describe their investigation of the influence of the rate of movement of the air on the scaling of 0·13% and 0·75% carbon steels, and show that at relatively low air velocities the scaling is variable. Further, the structure of the scale and its influence on the condition of the surface of the sheet after pickling are discussed.

Furnace Atmosphere. A. J. Fisher. (Iron and Steel Engineer, 1937, vol. 14, Apr., pp. 35–44). The author discusses the control of atmospheres in heat-treatment furnaces, and presents data on the scaling of steel and the equilibrium of gaseous mixtures, with special reference to the treatment of carbon steels.

Effect of Water Vapour on Hot Metal. A. G. Hotchkiss. (Metal Progress, 1937, vol. 31, Apr., pp. 375–379). The author discusses the presence of water vapour in furnace atmospheres used in bright annealing and other heat-treatment furnaces. Mention is made of a simple dew meter which gives direct visual indication of the dew point of a gas.

Controlled Heat Treating of Small Parts. H. P. Bristol. (Heat Treating and Forging, 1937, vol. 23, Mar., pp. 115–117). Particulars are given of the heat-treating department of the Bristol Company, at Waterbury, Connecticut.

Steel Heat-Treating Boxes and Pots. (Iron and Steel Industry, 1937, vol. 10, Apr., pp. 361–363; May, pp. 399–401). The types of steel suitable for containers used in the various heat-treatment processes are discussed.

The Hot Working and Heat Treatment of Carbon Tool Steels. R. A. Malmberg. (Industrial Heating, 1937, vol. 4, Apr., pp. 267–270). The conclusion of a series of articles in which the correct procedure for the hot-working and heat treatment of carbon tool steels are discussed. (*See* p. 20 A).

Modern Annealing Plant for a Continuous Mill. A. L. Hollinger and H. C. Weller. (Metal Progress, 1937, vol. 31, Apr., pp. 389–395). The author describes and illustrates the sheet-annealing department at the Lackawanna Plant of the Bethlehem Steel Company. The sheets are piled on a base and an inner cover is placed over the pile, sealed at the bottom and filled with a neutral gas. Over this is placed a heating unit in the form of a portable furnace cover. The furnace is fired by means of radiant heat tubes.

Present State of the Development of Continuous Normalising Furnaces for Thin Sheets. F. Lüth. (Stahl und Eisen, 1937, vol. 57, Apr. 8, pp. 365–372). The author reviews developments in German thin-sheet normalising furnaces which have taken place since 1930. Of particular note are the importance to which the walking-beam type of furnace has attained, the development of special normalising methods for automobile, deep-drawing, tinplate and commercial sheets, the improvement of the furnace outputs and details in the furnace structure.

Production of Acid Bessemer Rails. (Iron and Coal Trades Review, 1937, vol. 134, May 14, pp. 881–882). Particulars are given of the practice at the plant of the Workington Iron and Steel Co. for the heat treatment of rails according to the Sandberg method.

On the Velocity of Expansion Due to Martensitisation During Quenching of the Constructional Special Steels. A. Hatta. (Kinzoku no Kenkyu, 1937, vol. 14, Jan. 20, pp. 11–21). The author has observed the changes during quenching of a number of special steels by means of time-expansion curves. (In Japanese).

Heat Treatment of Steel by Direct Transformation from Austenite. E. S. Davenport. (Steel, 1937, vol. 100, Mar. 29, pp. 42–45). The author describes the "austempering" process and the properties developed in different steels by this treatment. This process consists essentially of heating steel to an appropriate temperature above the critical range to render it austenitic and then, instead of cooling it to room temperature in one of the conventional cooling media, transferring the steel to a hot quenching bath maintained at a predetermined, constant temperature below the critical range, but above about 300° F.; the steel is held at this temperature for a certain time to ensure the complete direct transformation of the austenite in the final product, after which the material may be cooled to atmospheric temperature in any convenient manner.

WELDING AND CUTTING

(Continued from pp. 21 A–22 A)

The Weldability of Ferrous and Non-Ferrous Metals. R. Smallman-Tew. (Electric Welding, 1937, vol. 6, Apr., pp. 113–116). The author lists the various types of ferrous and non-ferrous metals which can be strength-welded and reinforced by metallic arc welding, and those which can be reinforced, but which require the use of a special technique when strength welded. A reinforcing weld is carried out for the purpose of making good wear or damage. A strength weld is used for uniting two or more pieces of metal so that the joined piece or pieces are capable of withstanding stresses equal to those supported by the parent material.

Laboratory Researches on Welding and the Applications of Oxygen in Metallurgy. (Génie Civil, 1937, vol. 110, May 1, pp. 393–395; May 8, pp. 415–417). An account is given of the types of research carried out on the parent metal, filler rods and electrodes, and welded assemblies in the welding laboratory of the Société L'Air Liquide. Investigations on oxy-cutting, surface hardening with the blowpipe and metallisation are also mentioned.

Characteristics and Choice of Arc Welding Plant. R. Salelles. (Revue de la Soudure Autogène, 1937, vol. 29, May, pp. 102–108). A discussion of the electrical characteristics of various arrangements of arc-welding plant and of their various advantages for different cases.

Notes on the Application of Welding to Industry. F. W. Bowden. (Proceedings of the Cleveland Institution of Engineers, 1936–37, No. 1, pp. 19–32). A brief review of developments in the welding of iron and steel, with particular reference to various methods for providing protection for the metal while in the fluid state.

Making Resistance Welds with Separate Twin Electrodes. E. F. Ross. (Steel, 1937, vol. 100, Apr. 5, pp. 36–38, 72). Brief particulars are given of a new type of resistance welding machine known as the Flexi-Welder, which utilises two electrodes for the welding of automobile chassis. One of the electrodes is clamped to the body and the other is used to make the welds.

Welding Cast Steel—A Review of the Literature to November 1, 1936. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Apr. Supplement, pp. 2–11). A review of published information dealing with the welding of cast steel, and the physical properties of cast-steel welds.

Rail Welding. J. G. Hartley. (Welding Journal, 1937, vol. 16, Apr., pp. 7–10). The author describes equipment for the oxy-acetylene welding of rails, and outlines welding procedure.

Electric Welding of Stainless Steel. S. Sasaki. (Japan Nickel Review, 1937, vol. 5, Apr., pp. 172–197). The author deals with the properties of stainless steels at high temperatures and the changes in properties of this material during heating. He outlines precautions to be observed in the welding of stainless steel and describes the properties of the weld material.

Welding of Nickel and Nickel Alloys. H. Nishimura. (Japan Nickel Review, 1937, vol. 5, Apr., pp. 158–171). The author discusses the fundamentals of the welding of nickel and presents the results of various investigations on the welding of nickel and nickel alloys.

Steel Hard-Facing Procedure. E. E. Le Van. (Welding Journal, 1937, vol. 16, Apr., pp. 32–36). The author describes and illustrates procedure for the hard-facing of steel with alloys of cobalt, chromium and tungsten.

Hard Resurfacing with Stellite. (Revue de la Soudure Autogène, 1937, vol. 29, May, pp. 98–101). The building-up of worn parts and the replacement of soft spots on new articles by applying stellite by oxy-acetylene welding are described and illustrated.

Designing Welded Chemical Equipment. W. Spraragen. (Industrial and Engineering Chemistry, 1937, vol. 29, Apr., pp. 366–372). The author reviews developments in the application of welding to the construction of equipment used in the chemical industry.

Welding of High-Pressure Vessels and Boilers of Thick Plates. F. Faltus. (Revue de la Soudure Autogène, 1937, vol. 29, Apr., pp. 75–80). The author discusses the control tests to be made on the welds in high-pressure vessels and boilers made of thick plates and the type of results that should be obtained. Reference is made to Lloyd's Specification "Tentative requirements for fusion-welded pressure vessels intended for land purposes," and the American Society of Mechanical Engineers' "Boiler Code."

Welded Joints in Pressure Vessels. S. F. Dorey. (Journal of the Institution of Civil Engineers, 1937, Apr., pp. 621–686). The author summarises the present position regarding the adoption of welded joints in pressure vessels. He discusses design, workmanship, the material, welded joints, joint efficiencies, procedure control and testing of welded joints, heat treatment and X-ray examination.

The Behaviour of Welding Stresses in Containers under Internal Pressure. F. Bollenrath. (Stahl und Eisen, 1937, vol. 57, Apr. 15, pp. 389–398; Apr. 22, pp. 419–420). The author presents the results of an investigation of the behaviour of the welding stresses in two experimental drums, one gas-welded and the other arc-welded, on the application of internal pressures of up to 42 kg. per sq. cm.

Tensile Fluctuating-Stress Investigations on Specimens with Applied Welding Beads and on Welded Strap Joints. A. Thum,

F. Kaufmann and K. Schönrock. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Apr., pp. 469–476). The application of welding beads, whether longitudinally or transversely, to a flat bar lowers the tensile fluctuating-stress strength. With the longitudinal beads on one or on both sides and with the transverse beads on both sides, the strength is decreased by 40–50% as compared with the parent metal; the one-sided transverse bead behaved better. The cause of this decrease in the resistance to fluctuating stress was investigated in tests, in which the influence of the shape, the stresses and notch effects were examined.

Tests on strap joints of the obliquely-welded type devised by Schick gave unexpectedly low results for the resistance to tensile fluctuating stress. This is attributed to the stress condition set up during welding at the intersection of the two fillet welds. A form of strap is therefore proposed such that the stress peaks at the beginning or end of the welds set up on the application of the load are reduced by self-stresses, artificially introduced by the application of additional welding beads suitably placed; in this way the resistance to tensile fluctuating stress is brought up to approximately that of a simple butt weld.

Contribution to the Study of the Rôle of Nitrogen in Welds. A. Portevin and D. Séférian. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Mar., pp. 225–237). The third and final part of this paper (for the earlier instalment, *see* Journ. I. and S.I., 1937, No. I., p. 226 A). The authors discuss in detail the influence of various alloying elements on the absorption of nitrogen in steel, and the effect on the properties and microstructure produced thereby. They first deal with the influence of the usual elements in steel, and then turn to the consideration of the effects of the addition of aluminium, chromium, molybdenum, titanium, uranium, vanadium and zirconium.

MACHINING

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following:

E. SIEBEL: Plastic deformation.

E. K. HENRIKSEN: Internal stresses in machined surfaces.

H. OPITZ: Machinability of machine constructional materials.

DEMPSTER SMITH: Cutting tools.

R. WOXÉN: Some new results regarding the cutting of metals.

O. W. BOSTON: Cutting properties of metals.

The Machinability and Serviceability of Materials. F. Bacon. (Journal of the Institution of Production Engineers, 1937, vol. 16, Jan., pp. 1–11). The author discusses machinability; machinability charts; their use and limitations; the mechanism of chip formation; and the smoothness of surface produced. He then goes on to consider the influence of the surface condition, scratches, notches, punch marks, &c., on the fatigue resistance of the material and the formation of fatigue cracks. He points out the surprising fact that whereas the removal of metal in a gash, say, by filing is very weakening, a punch mark is almost innocuous; in the latter case, the plastic deformation markedly neutralises the stress concentration usually associated with a sharp notch. This fact led to Föppl's suggestion that the fatigue strength of a smooth polished surface could be raised by applying suitably distributed plastic distortion; the author describes Föppl's method of doing this by rolling the surface with hardened rollers under pressure, and gives details of the benefit obtained, as revealed in experiments.

Indication of the Cutting Capacity of Turning Tools by Means of Life/Cutting-Temperature Curves. H. Schallenbroch and H. Schaumann. (Stahl und Eisen, 1937, vol. 57, Apr. 29, pp. 441–444). The authors express the cutting capacity of turning tools by means of curves showing the relation between the tool life and the cutting temperature. These curves are derived by combining the results of tool-life/cutting-speed and cutting-temperature/cutting-speed curves, the temperatures for the latter being obtained by using pairs of tools so arranged as to act as thermocouples. Some test results obtained with three high-speed steels are given.

German Ingot Turning Lathes. (Iron and Steel Industry, 1937, vol. 10, pp. 304–305). Brief particulars are given of a lathe of German design for the turning of square ingots.

PROPERTIES AND TESTS

(Continued from pp. 31 A–41 A)

The Modern Aspects of Ferrous Metallurgy. J. H. Andrew. (Sheffield Society of Engineers and Metallurgists, Jan. 18, 1937). The author presents a short résumé of some recent developments in metallurgical research, and indicates how scientific research can be applied to industrial practice.

Complex Investigation of Metals and Alloys. L. Dlugatch. (Metallurgist, Russia, 1936, No. 1, pp. 115–128). The author discusses the necessity of testing metals by a " complex " method—*i.e.*, a method involving the simultaneous action of different agents (chemical, mechanical, &c.)—so as to obtain conditions analogous to those under which the metal will be placed in practice. (In Russian).

Relations between Stress and Reduction in Area for Tensile Tests of Metals. C. W. MacGregor. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 805; Metals Technology, 1937, vol. 4, Apr., No. 3). The author critically discusses certain methods of plotting stress-strain and stress/reduction-in-area curves for metals cold-worked in tension. Based on certain physical considerations, a different method of representing these relations is suggested in which the average true stress $\frac{P}{A}$ is plotted as a function of the true reduction in area $q' = \log \frac{A_0}{A}$, where A_0 is the original area and A the area at any load P. Tensile tests were made on various metals and such curves were plotted. For all of the steels tested and for most of the non-ferrous metals as well, the curve became a straight line from the point corresponding to the maximum load up to fracture, as distinguished from the curve usually obtained for $\frac{P}{A}$ plotted as a function of $q = \frac{A_0 - A}{A_0}$. This fact permitted the formulation of a new law giving the relation between the average true stress and the true reduction in area within the necking region of the tensile test. It also provided a relation between the tensile strength and the breaking strength such that one may now be easily calculated from the other. Various important advantages of this method of plotting were brought out. The anomalous behaviour of the commercially pure aluminium and copper tested was explained by means of X-rays, which showed a crack formed inside the necked portion of the test-piece. A comparison is made between the expression for the axial drawing stress for frictionless drawing as obtained by Sachs with the corresponding

expression for the increase in stress during the necking stage of a tensile test. Further, the application of the $(S - q')$ method of plotting to the drawing of brass wires and tubes is illustrated.

Some Measurements in the Region of the Yield Point of Mild Steel. G. Welter. (Metallwirtschaft, 1937, vol. 16, Apr. 9, pp. 345–348). The phenomena occurring at the yield point of mild steel, where the load suddenly drops on exceeding an upper limit, are yet not completely understood, in that it is not known whether—and, if so, to what extent—the experimental appliances (loading arrangement, stress measurement) may have an effect on the results. In particular, it is the dynamometer masses and the rate of flow of the test material which come into consideration as sources of error. In the experiments described the attempt was made to avoid, or at least to control accurately these two factors during the test. The stress was measured by observing the elastic elongation of a control bar connected between the specimen and the upper grip of the machine, and the elongation of the specimen was indicated by an extensometer. Specimens of 0·07% carbon steel were tested; the conditions were varied as follows: (*a*) normal working of the machine; (*b*) stationary pendulum dynamometer used with rigid loading appliance; (*c*) elastic loading with pendulum dynamometer; and (*d*) elastic loading without pendulum dynamometer. It appeared that the masses of the pendulum dynamometer had practically no influence on the results. On the other hand the shapes of the stress-elongation curves differed entirely according to whether a spring were inserted between the lower grip of the machine and the drive or not. With the spring there was no upper yield point followed by a lower one; first the lower limit appeared, at which the specimen began to flow slowly; then the upper yield point appeared only after the ability to flow, resulting from increasing stress, had been exhausted, before the material began again to elongate more slowly in relation to the load; no sudden flow of the metal was observed.

The Correlation of Impact Tests, and the Problem of Standardisation. E. J. Warlow-Davies and R. V. Southwell. (Proceedings of the Institution of Mechanical Engineers, 1936, vol. 134, pp. 507–545). It appears that more consistent and reliable results can be obtained from the Oxford impact testing machine, for the reason that "stray losses" have been eliminated from the energy account, and from the new specimen and method of loading, because only normal stresses act across the plane of fracture, and plastic distortion is confined to a narrow region immediately adjoining that plane. The energy of fracture is found to be closely proportional to the area of fracture. Hence the Oxford specimen (besides being much cheaper, since all machining is done in the lathe) appears to obviate most of the difficulties which have so far confronted attempts towards international standardisation. But the practical objection to a change of standards will remain unless it can be shown that the

same " impact property " of a material is measured in the Oxford as in, for example, the Izod test. Accordingly, tests have been made on 21 materials of widely different types, and the results are given in this paper. They show clearly that the Izod and Oxford impact figures are closely proportional to one another over the whole range (from about 50 to 900 ft.lb. per sq. in.) of the tests. Hence it can be asserted with some confidence that the Oxford specimen and method of loading could be standardised without fear of wasting the experience gained hitherto from Izod tests. The case for such standardisation rests on the low cost of manufacture of the Oxford specimen, and on the consistency and dimensional simplicity of the results obtained by its use.

The Cold-Deformation of the Surface of Materials in Different States of Preparation. H. Möller and A. Roth. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 4, pp. 61–63). Using specimens of steels St.C.10.61 and St.C.35.61, the surfaces were prepared in various ways (machining, lapping, polishing, &c.), and the depth and degree of cold-deformation of the surface were measured by means of X-ray reflection photograms; there was little difference between the two steels. The question of the depth of penetration of the deformation is important in making X-ray stress measurements, and it can be answered in general terms thus: With fine methods of surface working (planing, polishing) etching to a depth of 0·2–0·3 mm. is sufficient to remove the deformed layer, but with coarse methods of working it may be necessary to etch to a depth exceeding 0·5–0·6 mm.

The Temperature Changes during the Cold-Working of Metal Bars. G. Tammann and H. Warrentrup. (Zeitschrift für Metallkunde, 1937, vol. 29, Mar., pp. 84–88). When a test-piece is cold-worked, its temperature sinks in the elastic range and then rises sharply in the plastic range. This provides a means of determining the boundary between the elastic and plastic ranges for mild steel, even in the unworked condition. With metals such as copper and nickel, however, the two parts of the curve run into one another without a clear point of inflexion; only when the metal has been previously cold-worked does a kink appear, and it lies at the point corresponding to the load previously applied. This applies also to soft steel, but the kink obtained with unworked metal is still sufficiently sharply defined to be recognised.

The Reproducibility of the Results of the Determination of Elastic Stresses by X-Rays. H. Möller and F. Gisen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 4, pp. 57–59). Comparative tests on the accuracy and reproducibility of the results obtained in measuring elastic stresses by means of X-rays were carried out in two laboratories. It appears that owing to inaccuracies in measuring the films the measurement of the lattice constant may be in error to the extent of about $\pm 1 \times 10^{-4}$ Å.

Differences in the apparatus used in the two laboratories had no obvious effect on the results.

Engineering Defects in Industry. J. S. Caswell. (Institution of Civil Engineers, South Wales and Monmouthshire Association, Session 1936–1937). The author describes in detail some defects in engineering materials, and explains their immediate cause and the steps taken for their elimination.

Chipping of Tyres. R. Kühnel. (Stahl und Eisen, 1937, vol. 57, May 13, pp. 553–558). The author presents a survey of present-day knowledge regarding the causes of the chipping off of pieces of metal from railway wheel tyres. It appears that the trouble is very general, and occurs particularly on the running wheels of locomotives and tenders; this has nothing to do with the braking, and the choice of new materials has reduced the trouble very much; in some cases the cause lies in defective material. On wagon wheels the trouble is more of the nature of exfoliation, and long and heavy braking is the cause.

Fatigue Testing. R. T. Rolfe. (Iron and Steel Industry, 1937, vol. 10, Feb., pp. 259–262; Apr., pp. 345–350). The author discusses the mechanism of failure by fatigue, and illustrates some fatigue failures in service. Descriptions are also given of the various types of fatigue tests in use.

Endurance Bending and Tension-Compression Tests. I. G. Welter. (Wiadomości Instytutu Metalurgji i Metaloznawstwa, 1936, vol. 3, No. 3, pp. 149–156). In this, the first of a series of papers, the author presents a study of the stresses in a bar subjected to bending, and particularly of the effects occurring in the outer zone during slight plastic deformation, in order to obtain an insight into the mode of action of the bending fatigue testing machine. Small surface defects and blemishes, sometimes arising in the machining of the specimen, can have a marked influence on the test results obtained. Internal stresses in the specimens, generally present and arising out of the making and shaping of the materials, are discussed. The oxidation of the specimen, closely connected with the temperature rise during the test, causes chemical changes in the metal. The calculated surface fibre stresses for bending fatigue tests apply only to purely elastic stresses and are not equally applicable for all materials. The true stresses in the outer zone of the specimen and the exact depth to which they extend are not known. Finally, certain defects of a structural nature of the bending type of fatigue testing machine are considered.

Endurance Bending and Tension-Compression Tests. II. G. Welter. (Wiadomości Instytutu Metalurgji i Metaloznawstwa, 1936, vol. 3, No. 4, pp. 189–198). The tension-compression method of loading in fatigue tests has many advantages over the bending method. The entire cross-section of the specimen is uniformly stressed over the whole test length, so that surface defects and effects no longer play the important part that they do in bending tests;

further, the type of load applied can be varied as desired. The author describes in detail a new tension-compression machine which he has designed; in order that no bending of the specimen may occur its length is restricted and it is housed within a stout guide during the test, a window in the latter enabling the test length of the specimen to be observed. By means of this guide housing the conditions of testing (corrosive or oxidising, high or low temperatures) can be changed at will. Some test results obtained with this machine are recorded.

Endurance Bending and Tensile-Compressive Tests. III. G. Welter. (Wiadomości Instytutu Metalurgji i Metaloznawstwa, 1937, vol. 4, No. 1, pp. 30–39). On a newly-developed tensile-compressive fatigue testing machine tests were made to investigate the form of the fracture in relation to the surface condition of the specimen; the problem of devising a short-time testing method was also taken up and various methods were tried out. Tensile-compressive tests on steel specimens rubbed spirally or longitudinally with emery paper, in comparison with endurance bending tests, showed that the influence of the surface condition was not so great in the former as in the latter test. The heating-up of the tensile-compressive specimen during testing occurred in four stages: At first the temperature remained unaltered, and then it rose markedly; then followed a period during which it remained constant, but just before fracture it rose again still further. Changes in the mechanical properties and appearance of the surface of the specimen during the test are shown diagrammatically and in photographs, respectively. As short-time tests, three methods were tried, namely, measurement of the temperature of the specimen, observation of change in the appearance of the surface, and the use of a cone-shaped specimen. By combining the second and third methods the number of specimens required was reduced.

The Effect of Longitudinal Scratches Upon the Endurance Limit in Torsion of Spring Wire. F. P. Zimmerli. (Wire and Wire Products, 1937, vol. 12, Mar., pp. 133–138; Apr., pp. 185–191). The author describes an investigation carried out to ascertain the effects of longitudinal scratches upon the endurance limit in torsion of steel used in the production of helical springs. The results of the investigation are summarised as follows: Scratches may be measured accurately by plating the wire heavily with copper, polishing a cross-section, and examining the scratch with a microscope. Scratches on polished torsional fatigue test specimens lower the endurance limit of the material. The decrease in endurance limit caused by a scratch on the test specimen varies directly with the depth of the scratch and inversely with the radius of curvature at the bottom of the scratch. The decrease in endurance limit due to a scratch on the test specimen is much less than would be predicated by calculating the stress concentration at the bottom of the scratch. The endurance limit of wire determined by fatigue tests

on helical springs is only 60—65% of the endurance limit of the same wire in the form of polished torsional fatigue specimens. It is doutbful whether this difference is entirely due to the presence of surface scratches.

Experiments on the Torsional Fatigue Strength of Reduced, Grooved and Bored Shafts. W. Herold. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, May 1, pp. 505–509). The author presents the results of torsional fatigue tests made on specimens of various steels. The specimens were prepared from round bars; some had a reduced section; others were grooved longitudinally, in some cases a reduced section being provided as well; while yet others were drilled through in a direction at right angles to the axis of the test-piece. The strength properties of the materials and the torsional fatigue results obtained with the various types of specimen are set out in tables.

A New Method for the Estimation of the Modulus of Elasticity and Damping. F. Förster. (Zeitschrift für Metallkunde, 1937, vol. 29, Apr., pp. 109–115). The author describes a method, in which the acoustic properties of the object investigated are observed by electrical means, for the determination of the natural frequency of vibration and the damping capacity of metals shaped to any form, such as finished articles.

Modulus of Elasticity and Damping in Relation to the Condition of the Material. F. Förster and W. Köster. (Zeitschrift für Metallkunde, 1937, vol. 29, Apr., pp. 116–123). Using the testing method devised by Förster (*see* previous abstract), the authors have measured the elastic modulus and damping capacity of bar specimens vibrating freely in the transverse direction, the amplitude of vibration being very small. The specimens used included ferrous materials. As the temperature rises the elastic modulus decreases with increasing rapidity; the same applies in the reverse sense for the damping capacity so long as the mechanism of slip remains unchanged. During a polymorphic change or a change from the ordered to the disordered atomic arrangement, the elastic modulus varies with the transition from one condition to the other, but the damping is raised in the transformation range and even before the commencement of transformation. The ferromagnetic condition raises the damping capacity; below the Curie point the damping may decrease with the temperature, above the Curie point it increases in the usual way. In annealed metals the damping increases considerably with the grain size. The damping increases with decreasing resistance to deformation of the material. The hardness increase resulting from hardening or " ordering " a disordered solid solution raises the damping; in these processes the increase of the resistance to deformation corresponds to an increase of the damping. The elastic modulus increases on hardening iron-copper alloys and also on " ordering " iron-cobalt-chromium alloys. Cold-working lowers the elastic modulus and raises the

damping; on tempering, the damping decreases even at low temperatures owing to the relief of internal stresses, and reaches its lowest value just before the commencement of crystallisation; as new grains form, its value rises again slightly. The elastic modulus rises slowly during tempering, and suddenly when recrystallisation occurs. Internal stresses raise the damping; as they disappear on ageing or tempering the damping decreases. Cavities of any sort raise the damping capacity; under certain conditions their position in the material can be determined. Intercrystalline corrosion causes a heavy increase in the damping. Measurement of the damping capacity provides a non-destructive means of testing materials. Combined with the determination of the natural frequency it can be used to check the quality and uniformity of commercial products.

Non-Ageing Steels. (Automobiltechnische Zeitschrift, 1936, No. 12: Montanistische Rundschau, 1937, vol. 29, Apr. 16, Stahlbau-Technik, pp. 5–7). A brief discussion of the causes of ageing in steels and means for its avoidance.

A New Test for Relative Sliding Wear. D. S. Clark and R. B. Freeman. (Metal Progress, 1937, vol. 31, Apr., pp. 399–401). The authors outline an accelerated sliding wear test in which the wear resistance of a metal surface is determined by the magnitude of the force required to produce a scratch in conjunction with the width of the scratch made by a diamond of known dimensions.

The Testing of Magnet Steels. H. Lange. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 6, pp. 87–96). The ballistic demagnetisation factor of bar-shaped specimens with length-to-diameter ratios of less than 10 : 1 can be determined. With magnetically soft specimens it is possible to draw up the demagnetisation curve by measuring the apparent remanent induction of several bars with different dimensional ratios. Owing to the dependence of the demagnetisation factor on the permeability of the material this method of determination is not possible with magnet steels. The demagnetising field of magnet bars also can be measured by means of a magnetic potentiometer, and the author discusses the conditions under which it must be used and the accuracy of the results obtained.

The Thermochemistry of Alloys.—I. Direct Determination of the Heats of Formation of the Alloy Series Cobalt-Silicon, Iron-Aluminium, Cobalt-Aluminium, Nickel-Aluminium, Copper-Aluminium and Antimony-Zinc for the As-Cast Condition. W. Oelsen and W. Middel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 1, pp. 1–26). The heats of formation of the alloy series were determined by casting together the individual metals into a reaction vessel and measuring the heat generated in a water calorimeter. The values of the heats of reaction obtained are recorded. The heat-of-formation/concentration relationships of the alloys agree perfectly with the indications

of the constitutional diagrams. The commercially important solid solutions of iron, cobalt and nickel with silicon and aluminium gave very high heats of formation, which when calculated to the basis of one gramme-atom of silicon or aluminium were not lower than the heats of formation of the intermetallic compounds succeeding the solid solutions; consequently the elements aluminium and silicon are very strongly bound in these solid solutions. By means of the heat-content/concentration curves of the melts and the heats of formation of the alloys at room temperature the heats of mixing their melts were also determined. The conditions of chemical combination in the melts do not differ essentially from those in crystallised intermetallic compounds and solid solutions.

The Toughness at Low Temperatures of Materials containing Nickel. R. Hanel. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Apr. 3, pp. 410–414). For special purposes, particularly in the chemical industry, materials of high tensile strength which retain considerable toughness at very low temperatures are used. The author reviews the behaviour of nickel alloys in this respect. Nickel and its alloys with uniform solid solutions are still tough at the temperature of liquid air (— 192° C.). Steels, and particularly carbon steels, lose their hot toughness at temperatures between + 100° and — 180° C., depending on the alloy composition; high-chromium rustless steels are already brittle at room temperature, whereas 5% nickel steel, for instance, is still tough at — 190° C.; the other steels fall between these limits. Cast steel and welds with and without nickel behave similarly.

Permeability of Cast Iron to Hydrogen and Decarburisation by Hydrogen. W. Baukloh and F. Springorum. (Metallwirtschaft, 1937, vol. 16, May 7, pp. 446–449). Experiments on the permeability of cast iron to hydrogen and its decarburisation by that gas are described. Both the hydrogen permeability and the nature of the decarburisation were found to be considerably influenced by the form of the graphite. Increasing the silicon content increased both effects. The various modes of diffusion of hydrogen are discussed, and the conditions governing them are illustrated in micrographs. In conclusion, the authors touch on the difficulties that may be encountered in submitting cast iron to surface treatment by alitising.

Pig Iron. R. C. Tucker. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 29, pp. 347–349). The author discusses the properties of pig iron and their evaluation.

Valuation of Armco Iron by Slag Inclusions. N. Lewe, M. Shapiro and J. Malishenko. (Stal, 1936, No. 8, pp. 71–80). The authors discuss methods of determining slag inclusions. In the case of Armco iron, with very unstable slag inclusions and easily destroyed carbides, the electrolytic method, combined with the decomposition of the carbides by citric acid, gives better results

than the chlorine method. Even the first-named method, however, must be controlled by determining the total oxygen content of the metal by the vacuum fusion method. The authors further investigated the relations between the slag content and the mechanical properties of Armco iron. The notch toughness increases with increasing Al_2O_3 content, and decreases with rising FeO content in the slag. No simple relation exists between the notch toughness and the total slag content. Atmospheric and sea-water corrosion tests indicate that the content of FeO may be one of the main causes of the corrosion of Armco iron. (In Russian).

Nickel Cast Iron for Engineers. (Mond Nickel Co., Ltd., Bureau of Information on Nickel, Report B. 27). Details are given of the mechanical properties of typical nickel cast iron and their established applications are indicated.

Ingot Mould Life. J. Shaw. (Foundry Trade Journal, 1937, vol. 56, Apr. 15, pp. 308–310). A review of the work of various investigators on various factors, such as structure, composition and wall thickness, influencing the life of ingot moulds.

Some Innovations in the Tube Industry. M. Broich. (Internationale Röhrenindustrie, 1937, vol. 2, May, pp. 3–4). Owing to the shortage of certain metals in Germany, well filters made of copper, nickel or their alloys are forbidden. A new material called "Remanit" has been developed; it is a chromium-manganese type of steel (chromium 18%, manganese 9%, silicon 0·4%, carbon 0·1%), with a tensile strength of 70 kg. per sq. mm. and an elongation of 40%, and a specific gravity of 7·77. It can be easily worked. The rest of the article touches on a comparison of the properties of welded and weldless tubes, the making of tight joints in pipelines, "Mipolam" tubes for cold-water systems (to replace galvanised steel pipes; no details given) and the pipe-making method used at the Pittsfield Works of the General Electric Co.

New Alloys, of the Elinvar Type, Susceptible to Structural Hardening. P. Chevenard, L. Huguenin, X. Waché and A. Villachon. (Académie des Sciences, Apr. 19, 1937: Génie Civil, 1937, vol. 110, May 22, p. 470). The authors first touch on the defects, from the point of view of balance springs for chronometers, of elinvar and "Guillaume elinvar" (an elinvar containing carbon and tungsten); the elastic limit is not high enough. They then refer very briefly to tests they have made to solve this problem. They outline the difficulties in the way of a solution and then state that they have found two ways of solving the problem: (*a*) Structural hardening by precipitation of carbide in alloys of the Guillaume elinvar type containing further elements, such as vanadium, molybdenum, titanium, &c.; (*b*) Utilisation of the aluminium-titanium complex already used for producing austenites which will have a high strength at raised temperatures and will undergo structural hardening. The second solution, more sensitive than the first, gives higher elastic limits.

Copper and Its Alloys in Automobile Design. D. P. C. Neave. (Institution of Automobile Engineers: Iron and Steel Industry, 1937, vol. 10, Apr., pp. 351–352). The various copper irons and steels employed by the Ford Motor Co. for automobile parts are tabulated, particulars being given of their composition, heat treatment, hardness and applications.

Developments in Graphitic Steel for Tools and Dies. F. R. Bonte and M. Fleischmann. (Metal Progress, 1937, vol. 31, Apr., pp. 409–413). The authors describe the properties of a graphitic steel known as Graph-sil, which contains approximately 1·0% of silicon. In the as-rolled condition it is a hypereutectoid steel composed of pearlite and free cementite, with the possible appearance of small amounts of finely divided free graphite. The carbide phase is unstable because of the high silicon content of the steel, and consequently may be easily changed by heat treatment. A table of physical properties shows the different effects of air-cooling and furnace-cooling on the amount of combined carbon in the structure. Combined carbon decreases from about 0·60% to as low as 0·25% with an increase in temperature when the steel is furnace-cooled. On the other hand, it increases slightly if the material is air-cooled (from about 0·65 to 0·75% as the annealing temperature goes up from 1400° to 1700° F.). The time at heat after the samples have reached a uniform temperature apparently does not change the combined carbon to an appreciable extent. After fully annealing, the structure consists of free graphite surrounded by ferrite and the lamellar pearlite typical of a simple steel which has been cooled slowly from a relatively high temperature. The degree of graphite precipitation is controlled in a large measure by the annealing treatment. Normalising the fully annealed material from 1550° F. redissolves part of the graphite. The structure developed by normalising is shown. The combined carbon is increased to approximately the eutectoid value, and the structure is very similar to that of normalised eutectoid tool steel, having a dense pearlitic grain, except that it contains more or less free graphite. When annealed Graph-sil is normalised and again annealed at 1400° F. the combined carbon is slightly reduced, but the pearlite typical of the normalised condition is spheroidised to a degree commonly associated with good machining qualities. The quenching of graphitic steel from above the carbon change point after the graphite has been precipitated develops a martensitic structure. No difficulty has been experienced in the hot-rolling or forging of graphitic steel. The forging temperature should not exceed 2000° F. The physical properties of the material are tabulated. A second type of graphitic steel has also been developed. This material is known as Graph-mo, the composition of which is as follows: Carbon 1·45; manganese 0·35; phosphorus 0·008; sulphur 0·015; silicon 0·75; and molybdenum 0·25%.

Catalysts and Constructional Materials for Hydrogenation. H. Winter. (Glückauf, 1937, vol. 73, May 8, pp. 420–424). After an introductory account of the historical development and importance of catalysts, the author discusses the structure and composition (metals and their alloys) of the contact bodies for hydrogenation, how they attain their maximum activity, and the poisoning of catalysts. Methods of judging the efficiency of a given process are given. The author also discusses the constructional materials used for building hydrogenation plants; owing to the high pressures and temperatures employed, carbon steels have proved unsuitable, and low-carbon special steels such as ferro-nickel-chromium, ferro-tungsten, &c., are used for the heating tubes, the sheaths of the catalyst tubes and other parts.

The Quality of Steels to be used in the Construction of Autoclaves. C. Berthelot. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Mar., pp. 238–249). The author summarises and comments on the paper by R. J. Sarjant and T. H. Middleham on "Steels for Autoclaves," presented at the Chemical Engineering Congress of the World Power Congress in 1936. (*See* Journ. I. and S.I., 1936, No. II., p. 232 A).

The Development of Special Steels with Reference to the Raw-Materials Situation. E. Houdremont. (Stahl und Eisen, 1937, vol. 57, May 6, pp. 480–493). Having in mind the raw-materials situation in Germany, the author discusses the relation of laboratory test results to service results in regard to the demand for steels with high strength and toughness values; the development of case-hardening and heat-treatable steels, temperature-resistant and non-ageing structural steels, steels for pressing and hot-working, high-speed steels, corrosion- and heat-resisting steels, permanent magnet steels, magnetically soft and non-magnetic steels, primarily in order to reduce the use of nickel and tungsten; and the possibility of economising in the use of alloy elements by metallurgical measures and heat treatment. He concludes by stressing the need for close co-operation between the consumer and the producer.

The Development of Alloy 10. H. E. Koch. (Heat Treating and Forging, 1937, vol. 23, Mar., pp. 141–146). The properties and applications of Smith Alloy 10 are described. The composition of this alloy is chromium 37·5; aluminium 7·5; and iron 55·0%.

Copper Steels and Chromium-Silico-Manganese Steels. M. Braun. (Metallurgist, Russia, 1936, No. 1, pp. 67–82). The author describes the results of an investigation of the mechanical properties of a number of steels. The best among the non-casehardening steels were those containing chromium (0·1–0·3%) and silicon (1·2–1·3%), and silicon (1·2–1·5%) and manganese (1·2–1·4%), with 0·3–0·7% of carbon. Steel containing manganese (0·8–1·0%), silicon (1·2–1·4%), and chromium (1–1·2%) is much improved by the addition of 0·9–1·1% of copper. In the group of steels which are suitable for casehardening the best were the following two:

Carbon 0·17–0·23%, manganese 0·8–0·9%, chromium 1·0–1·2%, and copper 0·9–1·1%; and carbon 0·17–0·23%, manganese 0·9–1·1%, silicon 0·25–0·35%, chromium 1–1·2%, and copper 0·9–1·1%. (In Russian).

Nickel-Free Rustless Steels. H. Hougardy. (Maschinen-Bau/Betrieb, 1937, vol. 16, p. 241 : Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, May 8, pp. 543–544). The author reviews briefly the properties of some nickel-free rustless steels of the chromium, chromium-molybdenum and chromium-manganese types.

Rustless Steels for Ornamentation. A. Daubois. (Arts et Métiers, 1937, vol. 91, May, pp. 103–106). The author discusses the corrosion-resistant properties of chromium-nickel steels of the 18/8 type containing 0·04–0·1% of carbon. He first indicates in a general way the effect of heat treatment, working, welding, &c., on the corrosion resistance, and then explains his classification on the basis of the magnetic properties. Finally he refers to tests made to correlate the corrosion resistance with the magnetic properties. In his corrosion test the metal in question is placed in a vessel containing a saturated solution of salt; the carbon electrode from a Leclanché cell, with its container filled with manganese dioxide and coke, is also stood in the vessel, and the specimen and carbon electrode are short-circuited externally; the corrosion of the surface of the specimen in the depths of the solution is observed after 24 hr.

The Use of Special Alloys in the Glass Industry. M. Parkin and W. E. S. Turner. (Journal of the Society of Glass Technology, 1937, vol. 21, Apr., pp. 247–262). A survey, based largely on the results of a questionnaire sent to both suppliers and users of special alloys for blowpipes, moulds or parts thereof, machine parts, furnace metal work including lehrs, surface coatings, and miscellaneous uses. Some diversity of opinion was met with concerning the usefulness of a material for a given purpose, which may be due to unrecognised variables affecting the conditions. A noteworthy fact is the improvement recently in the quality of cast iron supplied, due in some cases to the introduction of small amounts of alloying material.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 42 A–48 A)

The Mechanical Development of the Microscope. R. S. Clay. (Journal of the Royal Microscopical Society, 1937, vol. 57, Mar., pp. 1–7). The author describes a new fine-adjustment for microscopes. The advantages of the instrument are pointed out.

A Note on the Mounting of Specimens in Bakelite. J. L. Everhart. (Metals and Alloys, 1937, vol. 8, Apr., p. 115). The author gives particulars of a method for the mounting of specimens in a bakelite resin to which an acid hardener is added. The method described is a modification of that of Taffs described in the Journal of the Royal Microscopical Society, 1936, vol. 56, pp. 300–306.

Contribution on the Carrying out of the Slag-Print Process. H. Dienbauer. (Berg- und Hüttenmännisches Jahrbuch, 1937, vol. 85, No. 1, pp. 25–27).—M. Niessner has developed a printing method for revealing oxide and non-metallic inclusions in steels. Gelatin paper is soaked for a few minutes in 5% hydrochloric acid; the greater part of the liquid is then removed by careful blotting, and the moist paper is then laid for a few seconds on the steel surface to be examined. The paper is then laid in a solution of potassium ferrocyanide (20 g. per litre) to develop the print. Intense blue coloration appears where non-metallic inclusions containing iron have been in contact with the paper. The present author discusses the process and points out as one of its defects the lack of definition of the outlines of the individual inclusion imprints. He suggests that this may be improved by adding 15% of sodium chloride to the 5% hydrochloric acid; comparative prints are reproduced to show the benefit of this salt addition. The author also discusses the mechanism of the production of these prints and the minimum particle size capable of being detected.

The Behaviour of Sulphides in the Slag-Print Process. R. Mitsche. (Berg- und Hüttenmännisches Jahrbuch, 1937, vol. 85, No. 1, pp. 22–24). Investigations on the behaviour of FeS- and MnS-rich non-metallic inclusions in the Niessner slag-print process (*see* preceding abstract) showed that basically both behave like iron-oxide inclusions. Prints of MnS-rich inclusions need to be exposed to the air for a considerably longer time in order to become clear. In order to reveal sulphides and oxides with certainty it is recommended that the prints be made on silver bromide paper soaked in hydrochloric acid, the print being then developed in a ferrocyanide solution. The advantages of this method are shown by illustrations.

Electromagnetic Testing Methods for Winding Cables. H. Wöhlbier. (Glückauf, 1937, vol. 73, Apr. 10, pp. 336–338). The author gives a short account of the magnetic-induction and the

oscillographic methods of examining winding cables for the detection of defects.

Hollow Anode Tube for X-Ray Irradiation. E. A. W. Müller. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Apr., pp. 481–483). A special type of X-ray tube, which can be used more conveniently than, and in places not accessible to, the usual type of tube, is described and illustrated.

Contribution on the Spatial Shape of Graphite. F. Roll. (Giesserei, 1937, vol. 24, Apr. 23, pp. 206–208). The author discusses briefly methods that have been tried in order to gain an insight into the spatial shape of graphite in cast iron. He reproduces five photographs of graphite flakes. No details are given, but apparently photographs of the graphite in sections of a cast iron, parallel to one another and a small distance apart are taken and then printed on to glass instead of paper; on placing the glasses one behind the other and binding them together an idea of the spatial arrangement of the graphite is obtained.

Local Formation of Martensite in Steel Wire. W. Püngel. (Stahl und Eisen, 1937, vol. 57, Apr. 8, pp. 373–374). The author describes an investigation of the occurrence of martensitic spots on the surface of steel wires in a haulage cable, which had been withdrawn from service after a short life on account of the formation of numerous cracks and fissures coinciding with positions of more or less severe wear. The conclusion is drawn that the martensite was formed as a result of local heating due to friction on the sheave and impact with steel struts of the framework. It is shown that martensite can be formed locally if the microsection for metallographic examination is not prepared properly, owing to excessive friction and temperature rise on the grinding wheel.

The Control of the Austenite Grain Size and the Physical Properties of the Steel. I. Feszczenko-Czopiwski and A. Kalinski. (Przeglad Mechaniczny, 1936, vol. 2, pp. 427–442: Stahl und Eisen, 1937, vol. 57, Apr. 1, pp. 355–356). In a basic 20-ton open-hearth furnace, various heats with controlled and uncontrolled austenite grain size were prepared; the carbon contents ranged from 0·32 to 0·57% (the nickel, chromium and copper were very low), and care was taken that the carbon in the charge was neither too high nor too low. Heavy ore additions and recarburisation must be avoided at all costs if the grain size is to be controlled later; likewise, deoxidation as complete as possible before tapping is essential for grain refinement. Two heats were deoxidised normally with ferro-manganese in the furnace and ferro-silicon in the ladle. Six were treated with low-silicon ferro-silicon and ferro-manganese in the furnace and with high-silicon ferro-silicon in the ladle (Herty's method). Four heats received 0·1–0·15 kg. of aluminium per ton of steel in the ladle before the ferro-silicon addition, and four more 0·45 kg. of aluminium per ton after the ferro-silicon addition. All heats were bottom-cast into 650-kg.

ingots with feeder heads. The greater aluminium addition and the presence of silicon did not increase the depth and size of the pipe—probably because the ingots were cast uphill with feeder heads. The increased aluminium and its addition after deoxidation with ferro-silicon did not increase the amount of alumina inclusions. Thorough deoxidation of the steel before tapping is essential for successful grain refinement; hence, care must be taken that part of the aluminium is not oxidised in the following slag, owing to its being added too late. Unlike McQuaid, who attributes the grain refinement to the alloying action of the aluminium, the authors assume that the finely-divided alumina particles act as nuclei. As the production of medium grain size is difficult, the authors suggest that fine grain size should be produced, which can then be rendered medium fine by suitable heat treatment. They found that the grain size was uniform and unchanging from the first ingot to the last of a given heat; the grain size can conveniently be determined in small test ingots cast at the same time. The austenite grain size in the steels treated with aluminium was constant and was unaffected by hot- or cold-working or by heat treatment, provided that the temperature of the commencement of grain growth (which varied up to 300° above Ac_3) was not exceeded; the grain size could not be diminished by these treatments. On quench-hardening, the fine-grained steels were superior to the coarse-grained, being insensitive to the period of heating and the quenching temperature, and having less tendency to form hardening cracks. After carburisation, the fine-grained steels had a thin hypereutectoid case and a comparatively fine-grained core, which did not always need a refining treatment; the optimum hardening temperature varied considerably for these steels, rising to 1175° in some cases. The fine-grained steels did not harden deeply, and for a given treatment their maximum hardness was somewhat lower than that of the coarse-grained steels. Regarding mechanical properties, the fine-grained steels had the advantage; the coarse-grained machined better, but the fine-grained were more wear-resistant, and the latter were less brittle after cold-working; in forging they filled the dies better and had a smooth surface afterwards. Whilst the fine-grained steels contained greater self-stresses after forging, they lost them readily on reheating.

The Transformation Kinetics of Austenite. VI.—The Decomposition of Austenite in Carbon Steels. I. F. Wever and H. Hänsel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 3, pp. 47–56). After the method for the isothermal investigation of transformation reactions had been tested on a series of alloy steels, it was possible to proceed with the examination of the transformations in pure carbon steels with the aid of a magnetic balance which had been further developed in the meantime. The new magnetic balance differed from the older one in that it enabled more rapidly occurring phenomena to be observed

and it could be used uninterruptedly over the greater temperature range of 700° to 150° C. In this temperature interval the transformation isotherms for a pure carbon steel (carbon 1·16%, silicon 0·10%, manganese 0·14%) were recorded, and the influence of the initial temperature, whether above or below the *SE*-line of the iron-carbon diagram, on the course of the transformation was observed. Contrary to the chromium-nickel steels examined earlier, in the carbon steels there was a uniform occurrence of the transformation between the pearlite and martensite points, characterised by the same time law for the course of the transformation over the entire temperature interval, with a maximum transformation velocity in the neighbourhood of 550° C. Further, secondary cementite in the initial state promoted the separation of ferromagnetic carbide even at lower temperatures of arrest and generally raised the rate of transformation. In the isothermal investigation of the martensite transformation it was possible to follow the momentary course of the formation of martensite and to measure its rate of transformation at temperatures up to about 30° below the martensite point. The kinetics of martensite formation fit in with the known scheme for the kinetics of other transformation phenomena; this shows that during ordinary quenching the true martensite point is invariably undercooled.

The Part Played by Undercooled Austenite in the Thermal Treatment of Steel. N. Grechko and M. Krjukov. (Metallurgist, Russia, 1936, No. 1, pp. 45–59). The authors have investigated the kinetics of the transformation of undercooled austenite and the influence of isothermal quenching and of step-quenching on the mechanical properties of six kinds of special steel. (In Russian).

The Transformation in the Solid State in Manganese Steels containing up to 1·2% C and 17% Mn. W. Tofaute and K. Linden. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 515–524). Using data taken from the literature, sections at constant temperature through the three-dimensional diagram of the iron-manganese-carbon system were drawn up, and it was found that in the temperature range 400–700° C., even with low manganese contents, a low-manganese α-phase is in equilibrium with a high-manganese γ-phase in the heterogeneous fields; it also appeared that iron carbide can dissolve manganese. By determining the magnetic saturation, the expansion behaviour and the electrical resistance, the ranges of the transformations in the solid state in pure iron-manganese alloys were determined. In investigations on the influence of carbon on the transformations, a dependency of the magnetic saturation on the tempering treatment similar to that in almost carbon-free iron-manganese alloys was found. With medium tempering temperatures evaluation of the saturation measurements was possible, which, for small concentration changes, gave confirmation of the data in the literature on the ternary system. The Brinell hardness tests and expansion curves taken—

supplementary to the saturation measurements—are of limited use for examining the transformation processes, and can be used to some extent for determining the A_3 range. The influence of the tempering treatment on the mechanical properties of three alloy series with 0·12, 0·32 and 0·8% of carbon and 2·4–6·4% of manganese was investigated. The strength rose almost linearly with the manganese content, more so with low than with medium carbon contents. With low carbon contents, besides a good yield ratio with tensile strengths of 50–90 kg. per sq. mm., elongations of 20% and notched-bar values of 20 kg.m. per sq. cm. were obtained.

New Investigations on Manganese. A. Schulze. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Apr. 17, pp. 463–464). The author reviews recent work on the transformations of very pure manganese and on the electrical conductivity, hardness and magnetic susceptibility of the various allotropes, carried out by a number of investigators.

Studies of the Widmanstätten Structure. VIII.—The Gamma-Alpha Transformation in Iron-Nickel Alloys. R. F. Mehl and G. Derge. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 797; Metals Technology, 1937, vol. 4, Apr., No. 3). The orientations of the α-phase in a meteorite with 7% of nickel and in iron-nickel alloys containing from 27 to 31% of nickel which have been transformed above room temperature can be described by the relationship of Kurdjumow and Sachs:

$$(111)\gamma//(110)\alpha$$
$$[110]\gamma//[111]\alpha$$

The orientations of the α-phase in iron alloys containing from 28·5 to 34% of nickel, which have been transformed at — 190°, can be described by the relationship of Nishiyama:

$$(111)\gamma//(110)\alpha$$
$$[211]\gamma//[110]\alpha$$

The orientations of the α-phase in iron alloys containing 31% of nickel lie between those predicted by Kurdjumow and Sachs and by Nishiyama when transformed at — 70° C. The temperature of transformation rather than the alloy composition or the occurrence of transitional lattices determines which mechanism shall operate. In the alloys studied in this investigation the Kurdjumow and Sachs mechanism operates at high temperatures and the Nishiyama mechanism operates at low temperatures.

On the Polymorphous Transformations of Iron in Iron-Zinc Alloys. B. N. Svetchnikoff and V. Gridneff. (Metallurgist, Russia, 1937, No. 1, pp. 35–39). The authors prepared ten alloys with 4, 5, 7, 8, 10, 13, 16, 19, 22·5 and 25% of zinc by sintering a mixture of powdered electrolytic iron and zinc of commercial purity (tin and antimony not exceeding 1%). The mixture was placed in an Armco-iron tube provided with a threaded plug and sintered;

then it was pressed and tempered at the following temperatures: 450° for 78 hr., 700° for 24 hr., 1000° for 24 hr., 750° for 12 hr. The tube walls were stripped off and the alloy specimen was subjected to dilatometric and microscopical analyses. Contrary to the assumptions of Tammann and Rydt and to the data obtained by Murakami and Ogava and F. Schramm, and in accordance with the conclusions of Jones and Feszczenko-Czopiwski, these alloys may be referred to as systems with a closed γ-field, the closing of the loop taking place at 15·5–17%. In no case did the authors succeed in the fixation of the γ-phase by quenching, nor could they discover the presence of it by X-ray analysis. This result also indicates that the alloys belong to systems with a closed γ-field. The raising of the transformation temperature on heating was observed also in alloys with a low zinc content (the end of the transformation), and the authors see no reason to attribute this to the effect of the accidental admixture of tin and antimony. The structure of a slowly cooled alloy containing 25% of zinc is very much like a eutectoid, and results probably from the decomposition of a supersaturated α-solution. In slowly cooled alloys containing less zinc (20·5 and 22·5% zinc) there are distinct symptoms of disperse precipitation.

The Alloys of the Iron-Chromium-Silicon System. B. N. Svetchnikoff and N. S. Alferova. (Theory and Practice of Metallurgy, Russia, 1937, No. 3). The authors have made and investigated sixty-one alloys containing up to 15% of chromium and up to 4·5% of silicon. Alloys weighing 300 g. each were made in a Tammann vacuum furnace from Armco iron, electrolytic chromium and 79% ferro-silicon. In the majority of cases the carbon content varied within 0·01–0·08%; in thirty alloys it did not exceed 0·06% and reached in exceptional cases 0·11–0·12%. The nitrogen content was found to be 0·0045–0·0054%. The alloys were investigated by thermal and dilatometric methods, microscopic and X-ray examination, and hardness tests of hardened and annealed specimens. The results of the investigation are shown in vertical sections of the space diagram for the following constant contents of chromium: 0·5%; 1%; 2%; 3%; 4%; 7·5%; 10% and 14·5% and in vertical sections for constant contents of silicon: 0·5%; 1%; 1·5%, separately for heating and cooling. After solidification the alloys represent a continuous series of α-solid solutions. The crystallisation range is very narrow. The initial crystallisation temperature is steadily lowered with increasing silicon content. The transformation $\alpha(\delta) \rightleftarrows \gamma$ in the solid state was studied in detail. Up to 4% of chromium the γ-phase loop constantly extends and with 4% of chromium the disappearance of the γ-phase takes place at about 3% silicon. Beginning with a chromium content of 7·5% the γ-phase steadily contracts simultaneously with a slackening of the loop at its lower part, especially in alloys with 7·3% of chromium. With 10% of chromium the disappearance of the

γ-phase is found to take place at about 1·8% silicon. Thus, up to a chromium content of from 4% to 7·3% the addition of chromium to iron-silicon alloys has the same effect as the addition of other elements that lower the A_3 point; it enlarges the γ-phase loop and in this respect silicon and chromium have an opposite influence. Further additions of chromium have an effect similar to that of those elements which raise the A_3 point. This effect combined with the influence of silicon gives rise to the contraction of the γ-phase loop. With a chromium content of 14·7% the γ-phase is entirely absent. This double action of chromium is of great interest for the investigation of the polymorphism of iron. The authors did not succeed in the fixation of the phase composition by hardening, and in all cases X-ray analysis showed only the α-phase in the hardened specimens. From the results obtained with regard to iron-zinc, iron-titanium, iron-silicon-chromium, iron-arsenic and iron-antimony alloys, the authors conclude that the fixation of the phase composition is impossible with all systems having a closed γ-phase field. On the basis of their experiments and evidence found in the literature, the authors have constructed the vertical section of the space diagram for a constant chromium content of 4–5% with the silicon content varying from 0·2 to 24%. (In Russian).

The Brown-Firth Research Laboratories. (Iron and Steel Industry, 1937, vol. 10, May, pp. 367–371). An illustrated account is given of the equipment of the Brown-Firth Research Laboratories, Sheffield.

CORROSION OF IRON AND STEEL

(Continued from pp. 49 A–53 A)

Corrosion Tests in the Laboratory of Professor Palmaer. Miss N. Goldowski. (Métaux et Corrosion, 1937, vol. 12, Mar., pp. 58–62). The author gives an account of the methods and apparatus used in the corrosion-testing laboratories of Professor Palmaer (which form part of the Institut Nobel, belonging to the Académie des Sciences) in studying the corrosion of ferrous materials, the conductivity of electrolytes, and the over-voltage of metals.

Sixth Corrosion Conference, Cologne, October 22, 1936. The proceedings of this conference, published under the title "Bericht über die Korrosionstagung, 1936, am 22. Oktober 1936 in Köln." [*See* p. 112 A].

The Principles of Corrosion Testing. C. W. Borgmann and R. B. Mears. (American Society for Testing Materials, Symposium on Corrosion Testing, Mar., 1937). The authors classify the various types of corrosion tests into three broad groups: (1) Laboratory, (2) field, (3) service. After a brief review of the theory of corrosion, they discuss various methods of estimating the rate of corrosion, together with the extent of corrosion. They stress the advantage of "special property" tests for "accelerated corrosion" tests. In conclusion the authors list certain tests on which, in their opinion, sufficient data are available to justify standardisation. These are divided into laboratory tests (impingement attack, intercrystalline corrosion, corrosion fatigue, partial immersion tests, spray tests, &c.) and field tests, including atmospheric exposure, soil corrosion and immersion tests. Tests which seem to require further work before standardisation, under the general heading of laboratory tests, include stress corrosion, film breakdown tests, crevice tests, total and alternate immersion tests, dezincification of brass and soil corrosion.

Atmospheric Corrosion Testing. H. S. Rawdon. (American Society for Testing Materials, Symposium on Corrosion Testing, Mar., 1937). The author outlines methods for and the precautions to be observed in conducting atmospheric tests. It is indicated that the results of atmospheric field exposure tests should always be correlated with the prevailing atmospheric conditions at the test location. A distinction must be drawn between tests aimed essentially to develop chemical characteristics and those intended for the acquisition of engineering corrosion data. A relatively large surface area with respect to the mass of the specimen is always advantageous for atmospheric corrosion tests. When the progress of corrosion is to be followed by change-of-weight determinations, a large area/weight ratio is required. The precision used in making change-of-weight

determinations must be varied to suit the purpose of the test. Weight determinations to 0·01 $\pm$ 0·005 g. are entirely satisfactory for a great deal of the work of this kind. All changes in weight should be calculated on the basis of unit of area and unit of time. The unit, mg. per sq. dm. per day, which has been suggested is not very satisfactory for ordinary atmospheric corrosion tests with respect to the unit of time. The conversion of change-of-weight data into units of " penetration per year " is not so necessary and helpful in atmospheric corrosion tests as in other forms of corrosion testing. Change-of-strength determinations should preferably be made on specimens machined from material after it has been corroded than on specimens which have corroded after being machined. A change in ductility is a more sensitive indicator of the effect of corrosion than the accompanying change in tensile strength. Tests of this kind are essential for evaluating properly the corrosion behaviour of certain types of metallic materials.

Standardisation of Salt Spray Tests. J. Pomey. (Métaux et Corrosion, 1937, vol. 12, Mar., pp. 47–51). The question of the standardisation of the salt spray corrosion test has been taken up by the Commission de Corrosion des Produits Métallurgiques pour l'Aéronautique, and a Sub-Committee on Standardisation has now fixed the temperature, *p*H value and composition of the corrosive agent to be used. A salt-spray apparatus, which is stated to function satisfactorily is illustrated diagrammatically and described.

Salt Spray Testing. E. H. Dix, jun., and J. J. Bowman. (American Society for Testing Materials, Symposium on Corrosion Testing, Mar., 1937). The authors state that experience with the salt spray test indicates that results can be made reasonably reproducible and of substantial value when properly interpreted. For the comparison of similar materials or as an acceptance test for certain classes of materials, the test has much to recommend it, while for comparisons of radically different materials or as an accurate indication of service life in other than marine atmospheres, its use may be hazardous. It is pointed out that to secure the best results from the salt spray test, standardisation of operating procedures appears desirable.

Alternate Immersion and Water-Line Tests. D. K. Crampton. (American Society for Testing Materials, Symposium on Corrosion Testing, Mar., 1937). The results which the author has obtained by the use of the alternate corrosion test have indicated relative rates of corrosion on several alloys which are very nearly in line with the relative behaviour of these alloys under generally similar service conditions.

Total Immersion Testing. R. L. McKay and F. L. LaQue. (American Society for Testing Materials, Symposium on Corrosion Testing, Mar., 1937). The authors in considering total immersion corrosion tests divided the experimental study of corrosion in liquids into two types, namely, theoretical studies and rate tests. They

indicate that standardisation in the field of theoretical studies is neither desirable nor possible, but standardisation with regard to rate tests is worth while, because it improves mutual understanding and is possible because it aids in obtaining reproducible results of practical use. Three important factors which should be controlled in total immersion tests are the temperature, aeration and velocity.

Soil Corrosion Testing. K. H. Logan, S. P. Ewing and I. A. Denison. (American Society for Testing Materials, Symposium on Corrosion Testing, Mar., 1937). The authors summarise their experience on the soil corrosion testing of pipes, and show that the nature of the soil is generally a more important factor than the exact composition of the metal. A rational procedure for testing the corrosion of metals in soils involves : (1) the corrosiveness of the soil ; (2) the relation between pit depth and area ; and (3) the relation between pit depth and time. The corrosiveness of a soil towards ferrous metals may be determined in the laboratory by measuring the voltage at various current densities of a cell in which the electrodes are steel and the electrolyte is the soil under test. The average current density corresponding to a range of voltage between 0 and 0·3 V. is expressed in terms of the average depth of the deepest pit to be expected on 1 sq. ft. at 12 years. By means of an equation in which the depth of the deepest pit on a given area is expressed as a function of (1) the corrosiveness of the soil, (2) the area exposed, and (3) the period of exposure, the estimated depth of pit may be calculated to the desired area and time. A general equation is given for the estimation of the number of holes, if any, in pipe as a function of the corrosiveness of the soil, time, and wall thickness. Empirical equations in which the depth of pit is expressed as power functions of the time and exposed area are described, and the constants of the equations are related to the properties of the soil. The slope of the pit-depth/time curve when plotted on logarithmic co-ordinates is shown to be determined largely by the aeration of the soil, the more poorly aerated the soil the steeper being the slope. The precision and range of application of the suggested procedure for soil corrosion tests are limited by imperfect understanding of certain features of soil corrosion, such as the exact nature of the relation connecting the pit depth with the exposed area. Although the method which has been described is not sufficiently well established to be adopted generally, it does constitute a basis on which a standard method might be developed.

Fundamental Requirements of Pipe Coatings. G. O. Thomas. (Commonwealth Engineer, 1937, vol. 24, Apr. 1, pp. 293–298). The problem of the protection of underground pipes is, in its practical phases, a complex one, as is shown by the divergent views and practices of the various pipe-using authorities throughout the world. Although it is certain that a coating which permanently resists the passage of water through itself will permanently protect the pipe, the converse is not necessarily true. Cement lining is an example of

good protection afforded by a permeable material, owing to the active chemical properties of the coating itself, which set up a condition unfavourable to the solution of iron from the walls of the pipe. A bituminous coating, being an inert substance, relies for its protective qualities on its ability to exclude water from the metal. If it becomes permeable, conditions are favourable to the commencement of corrosion, and its occurrence or otherwise depends on factors unrelated to the coating, such as soil chemistry and physics, electrical potential of the pipe relative to the soil, &c. If these are unfavourable to corrosion, there is no reason for using any coating at all. Failure of a coating or loss of resistance to water may occur in a number of ways, such as defects in manufacture, damage in transport and laying of the pipe, soil stress, loss of adhesion of the coating to the pipe, and absorption of water by the coating. In the author's opinion all coating failures other than those caused by force and faulty manufacture are due to water absorption. The author also described the results of an investigation carried out to measure the water absorption of a number of pipe coatings.

Fundamentals of the Method of Potential Measurements in Corrosion Research and in Topochemical Investigations. F. Müller. (Korrosion und Metallschutz, 1937, vol. 13, Apr.–May, pp. 109–113). The author first discusses local elements, their effects and factors influencing them, and the difficulties of carrying out researches in this difficult field of investigation and then describes two methods of making potential measurements, using thermionic valves, in which the amount of current drawn from the local element is extremely minute, thus avoiding errors introduced when heavier currents are used.

An Electrochemical Study of the Corrosion of Metals. J. B. Chloupek and V. Z. Daneš. (Korrosion und Metallschutz, 1937, vol. 13, Apr.–May, pp. 124–128). The authors describe an electrochemical method of studying the corrosion of metals; it is of the type in which a macroscopic model of a local element is realised. The conditions are maintained as nearly constant as possible, and the e.m.f. and other electrochemical characteristics of such an element are determined, from which conclusions as to the relative corrosion resistance of the metals can be drawn. In order that the electrochemical data obtained may be dependent as far as possible only on the metal specimen used, a non-polarising silver electrode (Ag/Ag_2SO_4/saturated Na_2SO_4) of constant potential is used as the cathode.

Coloroscopic Detection of Corrosion by Means of *p*H Indicator. Miss N. Goldowski. (Korrosion und Metallschutz, 1937, vol. 13, Apr.–May, pp. 128–131). As is well known, during the corrosion of a metal in an electrolyte the liquid near the cathodic parts of the specimen becomes acid and that near the anodic parts alkaline; an indicator in the liquid will reveal these differences by its change of colour; gelatine or a similar substance is added to reduce the

rate of diffusion of the ions. The author recommends the use of an indicator made up of the following ingredients: Cresolphthalein, 1·5 g.; phenolphthalein, 5 g.; methyl red, 4 g.; bromomethyl blue, 4 g.; naphtophthalein, 3·2 g.; methyl orange, 1 g.; and alcohol, 1000 c.c. When this indicator is added to the electrolyte the colour changes according to the hydrogen-ion concentration as follows:

*p*H value:	3	5	6	8	9	11
Colour:	red	orange	yellow	green	green-blue	violet

The electrolyte may with advantage be a 1% solution of sodium chloride. The method of applying the test is described, and coloured photographs of the results obtained on aluminium are reproduced; the applications of the test are discussed.

The Application of Potential Measurements to the Study of the Corrosion of Metals. L. Guitton. (Korrosion und Metallschutz, 1937, vol. 13, Apr.–May, pp. 131–144). The experiments described in this article were intended to increase the knowledge of the mechanism of corrosion by explaining a few exceptional cases. The author has carried out solution tests and potential measurements on a number of metals, including mild steel, 13% chromium steel and 18/9 chromium-nickel steel; the solution tests were made in hydrochloric, sulphuric and nitric acids of different strengths. The results are set out in diagrams and tabular form, and the solubility figures and solution potentials are compared and discussed. In conclusion the author reviews briefly the cases of metals with abnormal solubility values, among which are included rustless 13% chromium steel in concentrated sulphuric acid, this steel and 18/9 chromium-nickel steel in dilute nitric acid, and mild steel in concentrated nitric acid, and discusses abnormal passivity, the protective effect of anodic polarisation and oxidation, and abnormal activity.

The Theory of Corrosion Phenomena. V.—The Connection between the Setting-up of a Potential, the Corrosion and the Passivity of Metals in Aqueous Solutions. W. J. Müller. (Korrosion und Metallschutz, 1937, vol. 13, Apr.–May, pp. 144–157). The author first discusses the local current theory of the potential of metals, and the setting-up of a potential in the presence of oxidising reagents. The rest of the article is devoted to the application of the local current theory to the corrosion of metals, (*a*) in air-free aqueous solutions, and (*b*) in aqueous solutions containing air or oxidising agents.

The Corrosion of Metals and the Phenomena of Passivity. L. Colombier. (Revue de l'Industrie Minérale, 1937, No. 393, May 1, pp. 232–247). The author presents a general discussion of the phenomena of corrosion and passivity in the light of the general laws of electrochemistry and present-day knowledge of the constitution and properties of metals. In the first part he considers the

constitution of the atom, ionisation and corrosion; the second and third parts deal with accelerating and retarding effects of ionisation, whilst the last part is concerned with ionisation pressure and solution pressure.

Intercrystalline Corrosion of Carburised Ferro-Nickels containing Chromium, Cold-Worked after Hyperquenching. P. Chevenard and X. Waché. (Académie des Sciences, Apr. 12, 1937: Génie Civil, 1937, vol. 110, May 15, pp. 444–445). The authors describe the influence on the intercrystalline corrosion of carburised chromium-bearing ferro-nickels caused by the introduction of cold-working after hyperquenching and before tempering (*see* Chevenard, p. 51 A).

The Caustic Embrittlement of Boiler Plates. R. Rath. (Chaleu et Industrie, 1937, vol. 18, Mar., pp. 115–116). In order to be able to watch for caustic embrittlement in the plates of boilers, the author removes a few selected rivets and replaces them by pins screwed at each end; they are held in position by nuts under which soft copper washers are placed, so that they can be removed easily for observations to be made. The rivet hole is carefully polished and examined for cracks; these are rendered more apparent by etching. The author also discusses the prevention of caustic embrittlement by the addition of sodium sulphate or trisodium phosphate, and the amounts of these compounds required.

ANALYSIS

An Improvement in the Method for the Determination of Aluminium in the Presence of Iron. S. Ishimaru. (Science Reports of the Tôhoku Imperial University, 1936, vol. 25, Dec., pp. 780–784). The author first discusses four methods of determining aluminium in the presence of iron, indicating their advantages and disadvantages, and then suggests a combination of two of them : the slightly acid solution is treated first with sodium thiosulphate (Chancel's method); it is then cooled as quickly as possible to room temperature, and a 1 : 1 alcoholic solution of phenylhydrazine is added (Hess and Campbell's method); the precipitate is filtered off, washed and ignited to Al_2O_3. Test results indicate the accuracy of the method.

New Carbometer Controls Speed Production and Improve Quality. G. Soler. (Metal Progress, 1937, vol. 31, Feb., pp. 159–162, 200). The author describes the use of the Carbometer for determining carbon in steel, and discusses the advantages of this method in the control of melting operations.

The Determination of Cobalt. A New Method of Volumetric Determination and a New Method for Its Determination in Steel. B. S. Evans. (Analyst, 1937, vol. 62, May, pp. 363–377). The author describes a new volumetric method of determining cobalt which closely resembles the ordinary nickel titration. He also describes a method for titrating nickel in the presence of cobalt and a new method of separating cobalt from all metals interfering with the volumetric procedure. A survey is made of other metals precipitated by the reagent, and their non-interference with the method is demonstrated.

A Microchemical Determination of the Nitrogen in Steel, with Special Reference to the Investigation of Surfaces. P. Klinger and W. Koch. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Apr., pp. 463–468 : Technische Mitteilungen Krupp, 1937, vol. 5, May, pp. 61–67). The authors describe improvements which they have introduced into the method of estimating the nitrogen in steel by solution and distillation as ammonia, which render it very sensitive. They also give details of a process for dissolving off the surfaces of test-pieces to enable the nitrogen content of the surface layers to be estimated. The depth of penetration during nitriding in relation to the nitrogen content can be determined. Nitrogen contents as low as 0·0001% can be estimated.

The Determination of Sulphur in Addition Metals. C. Holthaus. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 511–514). This paper is a report by the Sub-Committee on the Analysis of Special Steels of the Chemists' Committee of the Verein deutscher

Eisenhüttenleute. On the basis of their investigations of the determination of sulphur in metals used as additions in steelmaking, the following recommendations are made : (1) The solution method is very suitable for determining the sulphur in metals soluble in nitric acid, such as molybdenum, manganese and cobalt. (2) The evolution method gives useful results with manganese and cobalt. In chromium only part of the sulphur is determined, although it is completely soluble in hydrochloric acid; the rest of the sulphur remains in the solution, and can be estimated after removal of the chromium. This method is unsuitable for other metals. (3) The fusion method gives good results with chromium and tungsten, but not with molybdenum. (4) The combustion method is perfectly satisfactory for manganese, cobalt and molybdenum, but is uncertain for chromium and tungsten. If titration is effected direct with a dilute soda solution, this method can also be used for estimating very small quantities of sulphur such as occur in high-purity aluminium, copper and nickel. (5) The reduction process proposed for ferro-molybdenum does not give good results with molybdenum metal. The tests relate throughout to the metals themselves and not to their alloys.

The Separation of Uranium, Zirconium and Titanium from Manganese, Cobalt and Nickel by Means of Pyridine. E. A. Ostroumow. (Annales de Chimie Analytique, 1937, vol. 19, Apr. 15, pp. 89–93). The pyridine, used as a feeble base, is employed in the form of a 20% aqueous solution. The principle of the method described is that from a weakly acid solution containing ammonium salts the pyridine precipitates uranium, zirconium and titanium quantitatively if the precipitation is carried out hot; the other metals (manganese, cobalt and nickel) remain in solution. The advantage of this method over the use of ammonia is that the absorption of the metals remaining in solution by the precipitate is so slight that a single precipitation suffices for their separation.

A Spectrophotometric Method for the Determination of Iron in Ores. J. P. Mehlig. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Apr. 15, pp. 162–163). The spectrophotometric method employing the molecular extinction coefficient has been satisfactorily applied to the determination of iron, by measuring the transmittancy of light at given wave-lengths through the system consisting of the amethyst-coloured complex formed by the addition of salicylic acid to ferric ions in acetic acid solution.

Complete Analysis of Chrome Iron Ore and Chromium-Bearing Refractory Materials. W. Erber. (Angewandte Chemie, 1937, vol. 50, May 22, pp. 382–383). The author first enumerates a number of methods, using acids or fused alkalis or salts for decomposing chrome iron ore, chromite and similar substances, that have been proposed, and then describes briefly a new method of opening up the material for analysis by fusing it with sodium pyrosulphate.

Determination of Zirconium in Steels with *n*-Propylarsonic Acid. H. H. Geist and G. C. Chandlee. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Apr. 15, pp. 169–170). Zirconium can be determined in steels with *n*-propylarsonic acid when present in amounts as low as 0·1% and in the presence of titanium, aluminium, chromium, cobalt, nickel, copper, uranium, vanadium, thorium, molybdenum, and tungsten. Tin is partially precipitated by this reagent, but the zirconium dioxide residues obtained upon ignition may be freed from tin oxide by adding powdered ammonium iodide and igniting.

Some Applications of Perchloric Acid in the Steelworks Laboratory. A. Raab. (Angewandte Chemie, 1937, vol. 50, May 1, p. 327). Short descriptions are given of methods of (*a*) estimating silicon, manganese and phosphorus in cast iron and plain steels, (*b*) determining the same elements and also chromium in alloy cast iron and steels, and (*c*) analysing high-speed steel, in which the metal samples are dissolved in perchloric acid.

International Association for Testing Materials, London Congress, Apr. 19–24, 1937. Among the papers presented in Group A, "Metals," were the following :

R. Castro : Methods of estimating the oxygen and oxides in iron and steel.

A. Skapski : Electrolytic extraction of the non-metallic inclusions in iron and steel.

H. Löfquist : Progress of knowledge on slag inclusions.

The Application of the Polarograph in the Steelworks Laboratory. I. The Determination of Copper, Nickel and Cobalt together in Steels. G. Thanheiser and G. Maassen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 2, pp. 27–46). **The Polarographic Determination of Copper, Nickel and Cobalt together in Steels.** G. Thanheiser and G. Maassen. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, Apr., pp. 441–460 : Angewandte Chemie, 1937, vol. 50, May 22, pp. 375–380). The principle of this analytical method is as follows : If a potential, steadily rising from zero to 2 V., be applied to two electrodes dipping in a solution of a metal salt, no current will flow until a certain minimum potential is applied. For every dissolved reducible material there is a minimum potential below which its deposition on the electrode, or its partial reduction in the case of multivalent ions, cannot take place; this minimum potential is called the potential of decomposition, deposition or reduction. But when solid electrodes are used a counter-potential is immediately set up; concentration polarisation occurs; for this reason mercury electrodes are used, a droplet or dropping electrode for the cathode and a large stationary pool of mercury for the anode. The author explains the principle of the method in detail, and describes the apparatus, the evaluation of the "polarogram," and the application of the method. The current

strength, which remains practically constant until the decomposition potential is reached, then rises to a higher value, at which it remains constant even though the potential is increased. Only so many ions are deposited on the cathode in unit time as can diffuse to the mercury droplets—that is, there is equilibrium between the rate of deposition and the velocity of diffusion of the reducible substance. The rate of diffusion is limited and depends on the concentration, the temperature and the viscosity of the solution. By maintaining the two latter factors constant, the current is proportional to the concentration of the reducible substance, and is called the saturation or diffusion current. The height to which the curve recording the current rises is also dependent on the size and velocity of the mercury droplets, but these factors can also be held constant; every new dropping electrode must be calibrated. Finally, the decomposition current is truly proportional to the concentration of the reducible substance when the solution contains a foreign electrolyte in a concentration at least ten times as great. The deposition potentials of the reducible materials are mostly known; from the current-potential curve the deposition potential for a given level on the curve can be determined, so that the polarograph can be used as a qualitative test.

Investigation of solutions of iron salts showed that the determination of other constituents of steel can be effected in the presence of ferrous iron only; trivalent iron must be absent; when estimating copper and nickel it is advantageous to remove the iron by precipitation with ammonia. In ammoniacal ammonium chloride solution copper is reduced to the monovalent state at — 0·34 V. and precipitated at — 0·54 V. Nickel can be estimated simultaneously, even in cobalt steels, because it is not deposited below — 1·1 V. For the estimation of nickel and cobalt together in steels, barium carbonate separation is employed; from the filtrate, nickel is deposited at — 0·95 V., and cobalt at — 1·25 V. Full details are given for carrying out these various determinations.

Contribution on the Spectro-Analytical Determination of Alloy Constituents. O. Schliessmann and K. Zänker. (Technische Mitteilungen Krupp, 1937, vol. 5, May, pp. 67–76). (*See* Journ. I. and S.I., 1937, No. I., p. 306 A.)

The Quantitative Spectrographic Determination of Carbon, Silicon, Manganese, Nickel, Chromium and Molybdenum in Iron and Steel. O. Schliessmann and K. Zänker. (Technische Mitteilungen Krupp, 1937, vol. 5, May, pp. 76–88). (*See* Journ. I. and S.I., 1937, No. I., p. 307 A.)

BOOK NOTICES

HEWITT, ABRAM S. "*Selected Writings of Abram S. Hewitt.*" Edited by Allan Nevins. With an Introduction by Nicholas Murray Butler. 8vo, pp. x + 414. New York, 1937: Columbia University Press; London: Oxford University Press, Humphrey Milford. (Price 17s. 6d.)

The papers contained in this volume are of unusual interest and importance. They record the writings of a man whose long life, varied activities and many services to industry and to the public earned him a great and enviable reputation. His papers and addresses cover numerous subjects, and those published here deal with iron and steel, politics, capital and labour, and education. A selected number of letters are also reprinted, which indicate Hewitt's many-sided interests. Of special interest to Members of this Institute is his report to the American Government as United States Commissioner to the Paris Exhibition of 1867. This dealt with "The Production of Iron and Steel and its Economic and Social Relations." This document was considered of such value that it was translated into many European languages. In addition to this, the volume contains the following papers on iron and steel: "A Century of American Mining and Metallurgy," Presidential Address before the American Institute of Mining Engineers, Philadelphia, July 20, 1876; "Iron and Labour," Presidential Address to the American Institute of Mining Engineers, Sept., 1890; "Sir Henry Bessemer," an Address to the British Iron and Steel Institute, Oct. 2, 1890.

Abram S. Hewitt, who was born in New York in 1822, was the son of an Englishman who went to America in 1790 as representative of the firm of Boulton and Watt. His connection with the iron and steel industry was as a partner in the firm of Cooper and Hewitt, who introduced the open-hearth process of steel manufacture in America. He was elected an Honorary Member of the Iron and Steel Institute in 1887, and his services in the improvement of methods for the manufacture of iron and steel were recognised in 1900 by the award of the Bessemer Gold Medal.

HORNER, J. G. "*Practical Metal Turning for Engineers.*" Fourth ed. revised by P. Gates. 8vo, pp. xi + 413. Illustrated. London, 1937: The Technical Press, Ltd. (Price 10s. 6d.)

Three editions of Horner's "Practical Metal Turning" have previously been published, and this fourth edition has been revised by Philip Gates. It deals with turning from the point of view of the engineer, and, although no attempt is made to treat the subject exhaustively, it is sufficiently comprehensive to cover all the important features. The relations between the turning section and the machine shop generally are considered in an introductory chapter, and the remainder of the book is divided into six sections dealing respectively with (1) the lathe, its work and the tools, (2) turning between centres, (3) work supported at one end, (4) internal work, (5) screw cutting and turret work, and (6) miscellaneous matters. Each section is in turn divided into chapters, and the four in the miscellaneous section are

concerned with (1) special work, measurement and grinding, (2) tool holders, (3) speeds, feeds and tool steels, and (4) some recent chucks. All aspects of the work described are illustrated by suitable sketches, of which there are more than five hundred. In general the book may be described as a comprehensive account of the principles and practice of turning for the use of production engineers, technical students and those amateurs who have mastered the principles of turning and desire fuller information on present practice and developments.

J. M. ROBERTSON.

JÄNECKE, E. "*Kurzgefasstes Handbuch aller Legierungen.*" 8vo, pp. xii + 493. Illustrated. Leipzig, 1937: Otto Spamer Verlag. (Price 52 RM.)

To the metallographist vainly trying to keep pace with the modern output of research on alloy systems the title of this work appears to promise more than could reasonably be achieved. The author has, however, condensed into the relatively modest number of pages at his disposal equilibrium diagrams, and descriptions of the characteristics, not only of all the binary alloys, but of a large number of ternary and even more complex alloys, including those containing iron, which maintain their exclusiveness by being awarded a separate section. In the first part of the book the author introduces his system of classification based on the number of possible phases which may crystallise from the molten alloy. Thus, binary systems in which a continuous series of solid solutions is formed, whatever the shape of the liquidus, constitute Type I. Type II. includes all eutectiferrous systems, with or without solid solubility, and also those alloys solidifying as two series of solid solutions separated by a peritectic. These two sub-divisions are treated separately, and a third section deals with all cases of limited miscibility. The formation of an intermetallic compound gives rise to three phases separating from an alloy of two pure metals, and Type III. covers such systems. Type IV. deals with the various combinations of four solid solutions, compounds, and pure metals separating from the molten alloy, and anything more complex than this is included in Type V. The advantage claimed for this classification is that all basically similar diagrams are grouped together, but it cannot be maintained that this is of primary importance, and the value of the work as a reference book to all the latest information on alloy systems would be enhanced by the provision of a simple alphabetical index. The ternary alloys are classified according to the most complex type of binary system included in the diagram, the ferrous ternary alloys being dealt with according to the effect of the other components on the α–γ transformation, and a special section is devoted to the alloys containing sulphur.

Throughout the volume the main features of the diagrams illustrated are discussed, but for more complete information reference must be made to the very full table of up-to-date papers given after each page of diagrams. The accurate reproduction of such a vast amount of material as is contained in this work places a heavy responsibility on the publisher, and it is perhaps invidious to record two errors, Fig. 3 being wrongly described in the text, and the melting point of zinc being obviously misprinted as 707° instead of 907° C. on p. 85. The output of books of an encyclopædic nature on metallurgical subjects has recently been considerable, particularly from Germany, and this latest addition to their number must soon rank as a standard reference work on alloy systems, and will render superfluous much laborious searching through technical journals and physical tables.

S. L. ROBERTON.

KORROSIONSTAGUNG, 1936. "*Bericht über die Korrosionstagung 1936 am 22. Oktober, 1936 in Köln.*" 8vo, pp. 61. Illustrated. Berlin, 1937 : V.D.I.-Verlag, G.m.b.H. (Price 3.75 RM.)

Since 1931, members of the Verein deutscher Eisenhüttenleute, the Verein deutscher Ingenieure and two or three other German scientific societies have held a series of annual conferences on corrosion, at which various aspects of the subject have been discussed. The fifth conference, held in Berlin in 1935, was attended by over 1000 delegates, and attracted a good deal of official and public attention. The promoting societies have, however, decided that it is desirable to have a rather longer interval than one year between the large official conferences and to hold smaller gatherings during the intervening periods, at which specialists and technicians could exchange views on the subject. The 6th conference, held at Cologne on October 22nd, 1936, is the first of the new series of smaller conferences, and the proceedings, which are reported in the volume under review, are to be regarded as of the nature of a round-table discussion. The general theme of the conference was the prevention of corrosion by the use of suitable methods of design, and seven papers were read illustrating the importance of this factor in the construction of railway rolling stock (E. Dähnick), motor vehicles (H.-U. Möller), chemical plant (P. Schafmeister and H. Braun), gas supply pipes (R. Hartmann), wire ropes (H. Herbst), structural steelwork (W. Adrian) and shipbuilding (E. Gödecken). Although the papers are necessarily condensed, each contains a good deal of practical and interesting information on the particular subject under consideration. What is perhaps the most important general principle to be followed in design from the point of view of avoiding corrosion is, however, *mutatis mutandis* well summarised for practically all fields of engineering by the following remarks of E. Gödecken, which refer more especially to shipbuilding: "As a fundamental principle, it is to be regarded as essential that the individual steel members of all parts of a ship's structure that are exposed directly to attack by sea-water or moist sea air should be joined together as tightly and smoothly as possible. It is essential to avoid places in which sea-water can collect." The necessity of avoiding seams, in which selective corrosion can occur as a result of the collection of moisture and corrosive agencies, is alluded to in one paper after another, and the main impression gained by the reader from the papers as a whole is the marked degree to which the introduction of welding has eliminated such undesirable seams in many fields of construction, and materially facilitated the application of protective coatings for maintenance, as a result of simplification of design.

J. C. HUDSON.

PORTEVIN, A., and P. BASTIEN. "*Réactifs d'Attaque Métallographique. Notions générales et formulaire relatifs aux réactifs micrographiques et macrographiques.*" 8vo, pp. xviii + 267. Illustrated. Paris, 1937 : Librairie Dunod. (Price, paper, 87.25 francs; bound, 102.25 francs.)

The objective of this treatise is to provide in a summarised form practical details of etching reagents for ferrous and non-ferrous materials, and methods of employing them in microscopical and macroscopical examinations. Readers will be familiar with previous publications, presented in similar form by Berglund and by the American Societies for Steel Treating and for Testing Materials. The authors explain that their work was well advanced when the previous treatises were published,

and that they have preferred to continue with their initial idea of presenting the subject-matter in an original and systematic manner. Their labours have provided us with a model book of reference which is thoroughly comprehensive and up to date. A series of chapters details in sequence etching reagents for ferrous alloys and for the non-ferrous alloys grouped according to the main constituent. Each reagent is neatly classified according to a number, the name of the original investigator and bibliographical reference, the composition, method of use and metallographical features indicated. The last is of exceptional merit and interest, and has been dealt with in a most thorough manner. Chapters I. and II., which deal with micro- and macro-etching reagents respectively for the ferrous alloys, cover 118 pages and quote 100 etching solutions and methods which may be employed. Supplementary data are given in appendices to each chapter, and include items such as polishing technique, heat tinting, electrolytic etching, tabular details of etching reagents and the resulting characteristics in examining non-metallic inclusions, &c. An introductory chapter outlines certain general considerations in metallographical work, whilst in a final chapter further practical details are quoted, such as etching reagents for nitrides, quantitative assessment of micro-constituents and grain size (illustrated). The four indexes cross reference the subject-matter most adequately according to the sequence of reagents described, the material or constituent examined, the etching reagent, and the name of the original investigator. It is clearly evident that the work is much more than a mere repetition of previously published treatises on this subject, and it should find a prominent place for everyday use in all metallurgical laboratories.

I. G. Slater.

Scheer, L. "*Was Ist Stahl?*" Einführung in die Stahlkunde für Jedermann. 8vo, pp. vi + 91. Illustrated. Berlin, 1937: Julius Springer. (Price 2.70 RM.)

This little book has been written for those engaged in the commercial side of the industry, and the author provides a most satisfactory answer to the interrogative title of his book. It is usual in works of this size, written for the non-technical man, to find that fundamental matters are neglected or distorted, with frequent recourse to doubtful analogy to cover up the gaps in the author's treatment of the subject, but in this book there is little or nothing to which the scientific metallurgist could object, and the information given, though concise, is always accurate. The manufacture of steel is not dealt with and the book opens with a short account of the allotropy of iron, including consideration of the space lattice, and goes on to describe the iron-carbon diagram and the microstructures associated with the standard heat treatments based on the diagram. This section is very thorough, and deals, among other things, with local surface hardening, age-hardening, and carburising. The second half of the book covers the alloy steels, introduced by a section describing the modification of the iron-carbon diagram with respect to the extent of the γ field brought about by the usual alloying additions. The special steels are dealt with individually, but special mention is given to stainless steels, high-speed steel, and the hard cutting alloys. It may not be out of place here to say that the conciseness and clarity with which this little volume is written make it an admirable primer for any metallurgist seeking to expand an elementary knowledge of German to cover technical matters. The printing and illustrations are of a very high standard.

S. L. Roberton.

SCHUBERT, H. "*Geschichte der Nassauischen Eisenindustrie von den Anfängen bis zur Zeit des dreissigjährigen Krieges.*" Unter Benutzung von Vorarbeiten des Professors Dr. Phil. Dr. Ing. Ludwig Beck. Bearbeitet von Dr. Hans Schubert. (Veröffentlichungen der Historischen Kommission für Nassau IX.) 8vo, pp. xiii + 534. Marburg, 1937: N. G. Elwert'sche Verlagsbuchhandlung.

This careful and exhaustive work is based on material collected by the late Professor Ludwig Beck, who was for a long time associated with the Nassau-Hesse iron and steel industries. This material has been augmented and revised by the author after a careful search through the state archives of Wiesbaden, Münster, Siegen, and other cities, and the result is a volume so carefully written and documented that it will be a fruitful source of accurate information to all those interested in the history and development of the iron and steel industry. The book is divided into two parts, each consisting of three sections. In the first part historical accounts are given of the growth of the industry in the regions of Siegen, Dillenburg, and the valleys of the Weil, Lahn, and Wisper, and the second part contains reproductions of the documentary sources from which these accounts have been compiled. The history covers the period from the earliest times up to 1618, which saw the outbreak of the Thirty Years' War. The subject is dealt with comprehensively for each region, such aspects as the early methods of smelting, mining and charcoal burning and metal working being covered in separate chapters. The author has not been content merely to chronicle events but relates the progress of the industry to the technical and economic circumstances prevailing at the time. The excellence of the work may, at least in part, be attributed to its origin in the notes of an eminent technician, and its completion by one who, in virtue of his position as Staatsarchivdirektor, had access to official records of the greatest importance.

S. L. ROBERTON.

SMITHELLS, C. J. "*Gases and Metals.*" An Introduction to the Study of Gas-Metal Equilibria. 8vo, pp. vii + 218. Illustrated. London, 1937: Chapman and Hall, Ltd. (Price 18s.)

Many books about metals are already in existence, and most new books are devoted either to bringing the subject matter of earlier works up to date, treating a subject more comprehensively than before, or collecting in a new way material already included in books. It is only occasionally that a book which deals for the first time with an important section of knowledge makes its appearance, and when it does it usually makes a welcome addition to the existing literature. This is certainly true of the present volume, for not only does it deal with a subject not previously considered in books, but it has been written by an author who has spent many years in the study of this subject. Gases play an important rôle in metallurgy. Reactions in which gases are involved are essential features of roasting, smelting and refining operations; the evolution of gas at solidification is one of the major phenomena associated with casting; important operations like carburising and nitriding depend on the diffusion of gas into metals, and the decay of metals at elevated temperatures is due to their reactions with gaseous environments. Had the author elected to consider the relations between gases and metals as a whole, his book would have become a general metallurgical textbook. He has, however, produced a much

more useful and original work by confining attention to the fundamental features of the physical behaviour of gases and metals in contact.

The book is divided into three chapters dealing respectively with the adsorption of gas by metal surfaces, the diffusion of gas through metals and the solution of gas in metals. These phenomena are of great importance in many branches of industry. Adsorption, for example, is the controlling factor in many catalytic processes, and it is also of importance in the manufacture of all kinds of vacuum devices such as electric lamps and thermionic valves, while diffusion and solution have an intimate connection with many metallurgical operations. All these phenomena have been investigated by numbers of workers, but different aspects have been studied by different groups, who have approached the subject from varied points of view. In consequence the results obtained in different fields have become scattered through scientific literature, workers on one aspect have tended to remain ignorant of the investigations of others, and the close relations between adsorption, diffusion and solution have not been appreciated. Dr. Smithells was in fact probably the first to draw attention to the importance of these relations, and his book is in a sense a full statement of views that he has already expressed in papers.

In each chapter the information available on the subject is reviewed, and a considerable amount of this will be entirely new to most metallurgists. Prevailing metallurgical opinion attaches great importance to the solution of gases, particularly by molten metals, but it is inclined to regard adsorption and diffusion as of much less concern. As, however, the gas that is eventually found in solution in metals is first adsorbed on the surface and then diffuses into the metal, none of these phenomena can be properly studied unless the others are taken into account. In assembling the information on the mechanism of adsorption, diffusion and solution, in explaining the effect on these of the various factors concerned, and in emphasising the intimate connection between these phenomena Dr. Smithells has made an important contribution to the advancement of metallurgical science. Many readers will realise immediately that the matter presented forces them to reconsider views that have been widely accepted, and it is almost certain that this reconsideration will eventually lead to investigations that will in turn result in advantageous changes in practical technique.

J. M. ROBERTSON.

WRETBLAD, P. E. "*Svenska Metallografförbundets Hårdhetshandbok.*" 8vo, pp. xvi + 331. Illustrated. Stockholm, 1937. A-B. Nordiska Bokhandeln. (Price, bound, 18 kronor; card covers, 16 kronor.)

In 1930 the Swedish Society for Metallography published their "Handbook of Etching," a volume, compiled by T. Berglund, containing an exhaustive survey of practically all the methods then known of etching metals for macrography and micrography. An English edition appeared in 1931. The Society has now produced the above equally exhaustive "Handbook on Hardness," which is the work of P. E. Wretblad. It is a digest of the literature published previously to 1936 dealing with the theoretical and practical aspects of various methods of hardness testing, with particular reference to the Brinell test. The work opens with a short summary of the history and meaning of the word hardness, followed by an attempt to explain the nature of the property on the basis of a consideration of its connection with certain fundamental properties of materials, together with a study of the theory of various hardening processes. The conclusion is reached that hardness is primarily a function of interatomic cohesion, and that in a

crystalline material the high hardness value calculated on this basis is never reached because of the ease with which slipping and mechanical twinning take place within the crystals. The more difficult it is for slipping to occur, the greater is the influence exerted by cohesion, and hence the harder the material is found to be. After a brief statement of the various methods of hardness testing, both static and dynamic, the author embarks on a long and detailed study of the Brinell test, in which, from the point of view of their influence on the result, he discusses the size, hardness and material of the ball, the factors governing the shape of the impression and methods of illuminating and measuring it, the rate of application of the load and the time during which it is maintained. Reference to the P/D^2 ratio leads on to an account of Meyer's law and "Meyer analysis." Consideration is then given to other types of static test, such as those employing pyramids, cones, &c., as indenting tools, and to dynamic methods. After some remarks on the dimensions of hardness test-pieces there follow notes on the application of the test to ferrous and non-ferrous materials, single metallic crystals, non-metallic substances, and materials at high and low temperatures. The book concludes with a survey of the relationship of Brinell numbers to other hardness numbers and to certain other mechanical and physical properties of materials, followed by summaries of the standard methods of testing used in Sweden and other countries. The text is amplified by twenty-three tables and eighty-one diagrams, the majority of which are collected together at the end. As the Rockwell method is widely used in Sweden, it is perhaps worth mentioning that sixteen of the diagrams and curves show the connection between the Brinell and Rockwell numbers for various ferrous and non-ferrous metals. The amount of information with which Mr. Wretblad has dealt may be judged from the fact that he gives a bibliography of something like 1500 references occupying 75 pages, *i.e.*, nearly a quarter of the book. No aspect of the technique of hardness testing has escaped notice, and the influence of every variation in procedure has been considered briefly or at length, as the case may be. In dealing with this material, the author has very wisely not allotted much space to the description or illustration of hardness-testing machines, being content to describe in comparatively few words the various types available. The handbook, being necessarily of a somewhat advanced nature, is essentially one for the research laboratories and research engineers of all metallurgical and engineering industries. It will undoubtedly be for many years Sweden's standard reference book on the subject of hardness testing, and Mr. Wretblad deserves unstinted praise for an excellent piece of work. It is pleasant to note that "Svenska Metallografförbundet" dedicates the book to the memory of a former Honorary Member—one Johan August Brinell.

W. H. DEARDEN.

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ORES—MINING AND TREATMENT

(Continued from p. 55 A)

The Studiengesellschaft Ore Dressing Process for Dogger Ores, with Reference to Results so far obtained in Large-Scale Operation. G. Sengfelder. (Stahl und Eisen, 1937, vol. 57, June 30, pp. 732–735). Earlier researches on the preparation of dogger ores have led to the foundation of the Studiengesellschaft für Doggererze in Bavaria, the objective of which is the development of processes and plant for the preparation of low-grade ores. Lengthy experiments have resulted in the perfecting of a dry-magnetic process for Oberfranken dogger ores, which has been successfully used in a newly built large-scale plant at Pegnitz. For the preparation of dogger ores from Baden and from the Salzgitter range a mixed method of dressing has been devised; this has given good test results, and large-scale plants are to be erected.

Beneficiating Low-Grade Iron Ores. E. W. Davis. (Steel, 1937, vol. 100, May 10, pp. 48–50, 88–89; May 24, pp. 38–41). The author describes the first magnetic ore-roasting furnace to be operated commercially in the Lake Superior iron ore district. The furnace is in operation at Cooley, Minnesota. A diagram of the furnace is given showing the arrangement of baffles to obtain uniform motion of the ore through the heating zone. The temperatures at various points in the furnace are also indicated. Particulars are included of detailed operation conditions.

The Sintering of Fine Ferro-Manganese Ore with the Elimination of Lead and Zinc. G. Yamada, T. Nakanishi and Y. Nakahara. (Memoirs of the College of Engineering, Kyoto Imperial University, 1937, vol. 10, Apr., pp. 34–43). The manganiferous iron ores from the Taiyo Mine, in Kemaman, Malay, contain a certain amount of lead and zinc. The authors describe in detail experiments on the sintering of these ores and the elimination of the lead and zinc, with a view to their subsequent use in the blast-furnace.

A Study of the Flotative Properties of Magnetite. W. E. Keck and P. Jasberg. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 801; Mining Technology, 1937, vol. 1, May, No. 3). The authors have studied the flotative properties of magnetite, using relatively pure natural material for their experiments. Magnetite was readily floated with sodium oleate, ammonium laurate and sodium oleyl sulphate. Sodium oleate was markedly superior to the other two collectors. The addition of terpineol, a frother, materially increased flotation with sodium oleate. With the saturated fatty acids (valeric, caproic, caprylic and stearic acids), flotation increased with the number of carbon atoms. Unsaturated oleic acid with 18 carbon atoms was a

better collector than saturated stearic acid, which also has 18 carbon atoms. Flotation of magnetite with sodium oleate was greatly depressed by slight *p*H changes caused by the addition of sodium hydroxide or sulphuric acid. In general, the flotative properties of magnetite were similar to those of hematite. Both minerals were readily flotated by the usual fatty acids and their soaps. With sodium oleate, specular hematite was slightly more flotatable than magnetite, and depression by an acid or a base was somewhat greater with magnetite than with hematite. When it was used with sodium oleate, sodium silicate was a strong depressor for magnetite. With small quantities of sodium oleate and terpineol, aluminium nitrate and zinc nitrate strongly depressed flotation, and copper and lead nitrates considerably activated it; whereas cobaltous, manganous and nickelous salts produced little change in flotation. The use of ferric nitrate with sodium oleate first activated flotation and then nearly completely depressed it with increasing quantities of the ferric salt. Under the same conditions, ferrous nitrate produced two cycles of activation and depression. Similar results were obtained when the following substitutions were made: (1) ferrous sulphate for ferrous nitrate, (2) ferric chloride or sulphate instead of ferric nitrate and (3) ammonium laurate instead of sodium oleate. The use of copper or lead nitrate with relatively large quantities of sodium oleate caused recurrent activation and depression of flotation. The presence of terpineol or of smaller quantities of sodium oleate tended to decrease this activation and depression.

REFRACTORY MATERIALS

(Continued from p. 56 A)

The Relation between Structure and Life of Silica Bricks in the Roof of an Open-Hearth Steel Furnace. V. L. Bosazza. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 37, Apr., pp. 526–532). The author has examined the texture and structure of some representative types of silica bricks, and shows how slag attack is influenced by the fineness and packing of the particles, and the porosity and nature of the pores of the bricks. To resist slag attack the brick should have particles that are angular to sub-angular in shape with a large proportion greater than 5 mm. in mean diameter. The particles should be packed in such a way that interlocking takes place. Furthermore, the presence of tridymite twins possessing crystal faces is preferable to the micro-granular crypto-crystalline cristobalite aggregates, as it reduces the capillary attraction between slag and silica brick.

Service of Roofs of Electric Furnaces and Production of Dinas Bricks in Verchissetsk. A. T. Jak and D. F. Burdakov. (Katshestvennaia Stal, 1936, No. 8–9, pp. 42–46). Particulars are given of the experience gained in Verchissetsk in the production of dinas bricks and their use for the construction of the roofs of electric furnaces. (In Russian).

Experiments on the Grading, Porosity and Permeability to Air of Sillimanite Bricks. F. H. Clews and A. T. Green. (Transactions of the Ceramic Society, 1937, vol. 36, June, No. 6, pp. 266–275). The distribution of sizes in the material classed as fine (through 80 mesh) exerts an important effect on the porosity and permeability to air of hand-tamped sillimanite products. For minimum permeability this fraction should consist of the finest possible size of grain, and for minimum porosity also a large proportion is necessary. The lowest porosity of the hand-made sillimanite specimens containing an addition of 10% of ball clay was 27·8%. The effect of the pressure during making in reducing the permeability to air is marked, but is more pronounced in the mix containing a higher proportion of fines. The hand-tamped product had a permeability value of 0·016, while a pressure of $9\frac{3}{4}$ tons per sq. in. reduced this to 0·0020. Evidence is given of the considerable alteration in the grading of sillimanite mixes caused by the use of high pressure in making, which raises the question whether the mix giving minimum porosity for hand moulding will necessarily yield the most dense product when machine pressed.

FUEL

(Continued from pp. 57 A–61 A)

Nomographic Determination of Calorific Values. R. McAdam. (Colliery Engineering, 1937, vol. 14, May, pp. 166–168). Charts are presented for calculating the calorific value of coal.

The Influence of the Process of Mixing on the Combustion of Gas and Air in Furnaces. I. K. Rummel. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 505–510; June, pp. 541–548). The space required for the combustion of gas and air as they mix in a furnace has not so far been adequately investigated; for this purpose the concept "flame" must be extended to include the "reaction space," which is not the same as the space occupied by the visible flame. The drawing of lines of equal content of carbon dioxide, oxygen, &c., in the reaction space does not give a satisfactory simple indication of the entire progress of the combustion. It is better to draw lines of equal content of air, burnt and unburnt fuel, the sum of which, related to the proportions of these three constituents in cu. m., is always equal to unity. A few particularly indicative lines of this kind divide the entire furnace space into characteristic "combustion fields." Further, surfaces of equal mixing (lines of equal "mixing factor"), which pass through the combustion space, can be developed. Finally, lines of equal "extent of combustion" are also important; this extent of combustion of gas and air can be represented by these invariable "combustion factor" lines. The "gas combustion factor" shows what percentage of the heating value, existing in a sample of gas before the combustion, is still retained after the combustion; the surfaces of equal gas combustion factor have the advantage that a definite amount of the total fuel is burnt within the space enclosed by them. With the aid of these novel modes of representation, the course of combustion and the composition of the furnace atmosphere will be investigated in the later part of this work.

The velocity of combustion is dependent on the rate of reaction of the ideal mixture, on the rate of diffusion and on the rate of the mechanical mixing by convection, which is essentially brought about by turbulence in practical furnaces. From the investigations it follows (1) that the reaction velocity of ideal mixtures, under the practical conditions of technical furnaces, can be regarded as almost infinitely great, that the diffusion depends very much on the thickness of the diffusing streams, and that, for thicknesses of the streams such as flow out of the burners in practical furnaces, the influence of diffusion is very much less than that of mechanical mixing by whirling, which, indeed, is the primary factor for the combustion process in large furnaces. (2) The combustion process can be

represented as the breaking-down of the streams flowing from the burners by mixing into whirling skeins of small thickness, in which intimate mixing is effected by diffusion. The course of combustion is thus to be regarded as a mixing process with reaction of the portions being mixed. (3) In the combustion of a gas stream with an air stream, starting from the contact surface of the two streams, the gas and air vortices mix together. The vortex surfaces mix with one another with simultaneous completion of the mixing by diffusion and expansion due to the temperature rise. The degree of mixing (*i.e.*, the concentration of the gas in the air and of the air in the gas) decreases with increasing distance from the contact surface of the two streams, but only to the outer boundary of the stream; from here, proceeding outwards, the concentration increases again, because, owing to the back drift acting outside the stream, vortices of high concentration are brought up, which mix with the vortices of lower concentration. (4) Because everything that mixes together burns instantly at temperatures above the ignition point and in a practically infinitely short time for the concentrations usual in furnaces, the combustion of gases can occur only at a two-dimensional surface, not in a three-dimensional space. Naturally, with whirling flow the surface is not smooth and stationary; it has a most complicated undulating shape and moves in progressive waves; nevertheless, the layer in which the combustion of the gas takes place is almost infinitely thin.

Matters are otherwise in the case of coal-dust firing. A certain time is necessary for the decompostion of the grains; the oxygen necessary for combustion can only reach the fuel by diffusion through the boundary layer adhering to the grains, and the products of distillation from the grain likewise have to pass outwards through this layer. The same applies to the soot produced by the cracking of hydrocarbons. The soot balls itself up into little spheres, which decompose only slowly. The size of these spheres is not inconsiderable; the ratio of the diameter of a soot sphere to that of a molecule of CO is about 1000 : 1. (5) If the combustion surface dealt with in (4) above did not continuously move in progressive waves as a result of the whirling motion, then it would coincide with the contact surface of the gas and air streams.

The experiments to be described in the following part of this paper have confirmed the correctness of the foregoing considerations.

Importance of Temperature Control in Vitreous Enamelling. H. Astbury. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1937, vol. 56, June 3, pp. 446–448). The author describes various types of apparatus used for the control of temperature during the enamelling process.

Action of Aqueous Alkali on a Bituminous Coal. L. Kasehagen. (Industrial and Engineering Chemistry, 1937, vol. 29, May, pp. 600–604). On heating at elevated temperatures and pressures in the presence of aqueous alkali, a bituminous coal is converted into

coke-like residues which have lower percentages of oxygen and of hydrogen than the coal itself. Results of the alkali treatments throw some light on the chemical constitution of coal. Neutral, viscous liquids and solid phenolic substances of high molecular weight are by-products of the treatments. By the proper choice of conditions, residues which have hydrogen percentages as high as, but oxygen percentages much lower than, those of the coal can be formed. Hydrogenation of these residues forms products more hydrocarbon-like in nature than does a similar hydrogenation of the coal itself. Although the data presented do not appear to have immediate practical application, in the future there may be a possible commercial use of residues produced by the alkali treatment of bituminous coal as raw materials for hydrogenation.

The Drying of Fine Coals by Centrifuging. P. Rzezacz. (Glückauf, 1937, vol. 73, May 29, pp. 496–507). The author reviews various modern types of centrifuges used for drying fine coals and gives an account of experiences gained with them.

New Central Coking Plant of the Barnsley District Coking Co., Ltd. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Apr., pp. 53–58, 62; May, pp. 73–77). A complete illustrated description is given of the layout and equipment of the Worsborough plant of the Barnsley District Coking Co., Ltd. The coking installation consists of a battery of 51 Woodall-Duckham Becker ovens.

The Heat Insulation of Coke-Oven Tops. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, May, pp. 67–69). The problem of insulating coke-oven roofs is discussed and the dangers of excessive insulation are pointed out.

Steam-Driven Gas Compressor for Coking Plant. (Engineering, 1937, vol. 143, May 14, pp. 550–552).—The design of a steam-driven gas compressor is described and illustrated. Two of these compressors have been installed in a coking plant in the North of England. Each compressor has a capacity of 3300 cu. ft. per min. at 10–15 lb. per sq. in. delivery pressure, and is designed to draw 4·4 million cu. ft. per 24 hr. of crude coke-oven gas with a specific gravity of 0·5 (air = 1) from gas holders, and deliver it through five miles of pipe-line, the final pressure being 2 lb. per sq. in. measured at normal temperature and pressure. The compressors are of the two-crank tandem type, and are supplied with steam at a pressure of 140 lb. per sq. in., exhausting to a back pressure of 10 lb. per sq. in. They run at a speed of 140 r.p.m.

Apparatus for Precise Plasticity Measurements at High Temperatures. H. K. Griffin and H. H. Storch. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, June 15, pp. 280–286). An instrument for precise measurements of plasticity at elevated temperatures is described. Adequate apparatus is included for avoiding eccentric loading. Measurements made on Pittsburgh and Alma seam coals show that the truly plastic proper-

ties of these coals are very transient, the life period being of the order of 1 min. at 460° C. Measurements of deformations proportional to the load were obtained at 410° C. An analysis of these data indicates that the deformations are elastic rather than plastic in character. Measurements on the deformation of the solid plus oily bitumen (obtained by benzene extraction) of Pittsburgh seam coal at 120° C. show that this is a truly plastic material.

Coking Properties and Classification of Coals. L. M. Sapozhnikov. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Mar., pp. 42–44; Apr., pp. 95–97). The author outlines researches conducted on Russian coals with a view to explaining their application to coke-making purposes.

Coke from Illinois Coal. G. Thiessen. (Industrial and Engineering Chemistry, 1937, vol. 29, May, pp. 506–511). The author describes coking tests of Illinois coal carried out in a Knowles sole-flue oven. In this type of oven coke can be produced, the lower two-thirds of which has the properties of a high-temperature, low-volatile coke, and the upper third the characteristics of a low-temperature coke. Analyses of the coals coked, the coke and gas produced, and of horizontal sections of the coke at various intervals from the oven floor are presented.

Improvements in the Wash-Oil Process. W. Demann. (Glückauf, 1937, vol. 73, June 26, pp. 593–605). The author describes recent improvements in the process for the recovery of benzol from gas by means of wash oils.

The Use of the Gas-Producer in Steelmaking. Its History. Its Present State. Its Future. C. Le Chatelier. (Chimie et Industrie, 1937, vol. 37, May, pp. 835–852). The author first presents a short history of the gas-producer, and then makes a critical examination of its state of development. He asserts that at the moment the producer is suffering a setback, and discusses various directions in which progress might be made in regard to efficiency, regularity of operation and economy.

Generation of Water-Gas from Low-Temperature Coke. G. Wilke. (Technische Mitteilungen Krupp, 1937, vol. 5, Apr., pp. 44–49). In a large producer, 3·6 m. in dia., low-temperature coke was used for making water-gas under works conditions. The resulting gas contained 53·5% of hydrogen and 36% of carbon monoxide, and was very suitable for the manufacture of hydrogen-rich synthetic gas mixtures or of hydrogen; 70% of the calorific value of the coke was made available in the water-gas and excess steam. About 67% of the volatile matter of the coke was found in the water-gas. The decomposition of the steam in the producer was much greater than when using high-temperature coke. No operating difficulties were encountered.

Gas Distribution at River Rouge Plant, Ford Motor Co. F. J. Harlow. (Iron and Steel Engineer, 1937, vol. 14, May, pp. 17–25). The author describes the gas distribution and control systems in

operation at the steel and glass plants of the Ford Motor Co., River Rouge. The fuel requirements of the various departments are shown.

Innovations in Gas Engine Cylinders. F. Reimer. (Stahl und Eisen, 1937, vol. 57, May 20, pp. 569–577). The author first shows that the gas engine is at least the equal of the steam turbine as a prime mover, even in new plants, provided that the amortisation is adjusted to suit its actual life; old engines which have been completely written off continue to work very efficiently, and the greater maintenance costs are economically justified. The author then discusses recent innovations in the design and construction of gas engines, particularly in regard to the cylinders and their cooling, and the valves.

High-Pressure Spherical Gas Holder at Stettin. E. Homborg and G. Riempp. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, June 12, pp. 695–697). An illustrated account is given of the structural details and construction of a welded 5000-cu. m. spherical gas holder, 21·3 m. in dia., which will withstand internal pressure up to 5 atm.

Extraction of the Hydrogen from Coke-Oven Gas used for the Manufacture of Synthetic Petrol. C. Berthelot. (Génie Civil, 1937, vol. 110, May 22, pp. 459–461). The author describes the Messer method of extracting hydrogen from coke-oven gas. The gas is first purified to remove CO_2 and sulphur compounds, after which it is dried at $-50°$ C.; the hydrocarbons are next condensed out, followed by the carbon monoxide; finally the temperature is lowered to $-210°$ C. in order to liquefy the nitrogen.

The Rotavac Oil Burner. (Engineering, 1937, vol. 143, May 21, pp. 579–580). The design and operation of this type of burner are described and illustrated.

PRODUCTION OF IRON

(Continued from p. 62 A–63 A)

Setting New Standards for Blast-Furnace Runs. G. G. Coolidge. (Blast Furnace and Steel Plant, 1937, vol. 25, May, pp. 493–495). The author recounts some record campaigns achieved with American blast-furnaces in the past, and refers to the use of power-pressed brick for ensuring longer life of blast-furnace linings.

The Reduction of Metallic Oxides by Carbon and Coke. A. Krupkowski. (Annales de l'Académie des Sciences Techniques à Varsovie, 1936, vol. 3, pp. 238–263). The author presents an account of the study of the kinetics of the reduction of metallic oxides and ores by charcoal or coke. The method employed consisted in placing the mixture of oxide plus carbon in a furnace at constant or rising temperature, and noting simultaneously the temperature and the rate of evolution of gas, at the same time determining the chemical composition of the gas. The tests reported were made on Cu_2O, CuO, NiO and Fe_2O_3. The reduction of Fe_2O_3 by charcoal takes place in three stages : $Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow FeO \longrightarrow Fe$. The first reaction, with a very weak thermal effect, occurs within the range 610–820° ($CO_2 = 99\%$); the other two are endothermic and their upper temperature limits of isothermal reduction are 820° ($CO_2 = 70\%$) and 920° ($CO_2 = 30\%$), respectively. When using coke as the reducing agent the temperatures for the three stages are higher—namely, 685–950°, 950° and 1000° C. Iron ores are reduced in the same way as pure Fe_2O_3; the temperatures for the three stages are very slightly lower when using coke as the reducing agent.

Burdening of Furnaces for Ferro-Silicon. J. S. Shedrovitsky. (Katshestvennaia Stal, 1936, No. 8–9, pp. 53–57). The author presents technological recommendations regarding the burdening of furnaces making ferro-silicon. (In Russian).

FOUNDRY PRACTICE

(Continued from pp. 64 A–65 A)

A Small Oil-fired Rotary Furnace. E. W. Wynn. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, May 27, pp. 426–430). Illustrated particulars are given of the constructional arrangement of a small oil-fired rotary furnace for the melting of cast iron, and the annealing of malleable castings. Micrographs are included of some of the types of iron produced in this furnace.

Annealing Time for Malleable is Reduced to 45–50 Hours. E. Bremer. (Foundry, 1937, vol. 65, May, pp. 42–43, 133–134). An account is given of the practice at the plant of the Wagner Malleable Iron Co., Decatur, Illinois, for the annealing of malleable castings.

Testing Foundry Sands. W. Y. Buchanan. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, May 20, pp. 406–408, 414; May 27, pp. 423–425). A comparison is made of the methods adopted by the American Foundrymen's Association and the British Cast Iron Research Association for the testing of foundry sands.

Factors Affecting the Ramming Density of Sand. J. Dearden. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, June 3, pp. 439, 442). The author discusses the effect of ramming, composition, moisture and other factors on the density of moulding sand.

Mould Facings for Cast-Iron and their Effects upon Vitreous Enamel. H. McNair. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1937, vol. 56, June 3, pp. 448–450, 452). The author presents the results of an investigation of a number of moulding sands and facings used in cast-iron founding to determine their effect upon enamel during the process of application.

The Need for Scientific Treatment of Moulding Machine Problems. U. Lohse. (Giesserei, 1937, vol. 24, May 21, pp. 276–277). The author reviews briefly the present position of the scientific basis of the construction of moulding machines, and enumerates a dozen general problems on which research is needed.

Mounting Patterns on Plate and Plaster. C. J. Hinton. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, May 27, pp. 421–422). The author illustrates several examples of methods for the mounting of patterns on plates and plaster.

The Production of Ingot-Mould Castings. R. Ballantine. (Institute of British Foundrymen: Foundry Trade Journal, 1936, vol. 56, June 24, pp. 530–532; vol. 57, July 1, pp. 5–6; July 8, pp. 32–34). The paper is a continuation of a previous one in which the author surveys developments in the production of ingot moulds.

In the present paper the author discusses hot tears, proper gating, and flaking or corner segregation. Various types of mould castings are illustrated.

Production of Rolls for Cold Rolling Mills. P. P. Chichikanov, K. K. Vinogradov, and V. J. Chuprakov. (Metal Industry Herald, 1936, No. 14, pp. 39–51). The authors describe in detail the production of chromium-steel rolls for cold-rolling, with a diameter up to 45 cm., by the Ural Heavy Machine Building Works. The most difficult stage in production is the heat treatment, to assure a high uniform hardness of the working surface, a tough core, and a smooth transition from the hardened layer of the barrel to the core and to the soft journals. (In Russian).

Physical Factors in the Casting of Metals. C. H. Desch. (Third Edward Williams Lecture, Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, June 17, pp. 505–508). In the casting of metals two kinds of factors affect the flowing power. One set includes the form, material and surface of the mould, the casting head, and the degree of superheating of the metal before pouring. The other set involves the properties of the metal or alloy, such as viscosity, surface tension, gas content, formation of surface films, as of oxide or nitride, the range over which solidification takes place, change of volume during solidification, and crystal thrust. The author discusses the second set of conditions.

Turning Cast Iron Borings to Profitable Account. (Foundry Trade Journal, 1937, vol. 56, Apr. 1, p. 268). Illustrated particulars are given of the "President" press for the briquetting of cast-iron borings.

Steel Foundry Crane. (Engineer, 1937, vol. 163, Apr. 9, p. 418). Brief illustrated particulars are given of the arrangement of the two-grab steel foundry crane installed at the plant of the Appleby-Frodingham Steel Co., Ltd.

Foundry Conveyor System Features Compact Installation. (Iron Age, 1937, vol. 139, Apr. 29, pp. 48–49). Brief illustrated particulars are given of a conveyor system installed at an American foundry.

Time Control in the Manufacture of Repetitive Castings. B. Brown. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 56, Apr. 8, pp. 297–298, 300; Apr. 15, pp. 313–315). The author points out the importance of time control and discusses its application to various foundry operations.

Nomograms in a Pipe Foundry. C. K. Donoho. (Metals and Alloys, 1937, vol. 8, Apr., pp. 93–97). The author explains the general principles of the common types of nomograms, and gives a few practical examples of their use in calculating foundry mixtures, the weight of iron in ladles and the weight and thickness of pipe castings.

PRODUCTION OF STEEL

(Continued from pp. 66 A–69 A)

Influence of the Shape of the Basic Bessemer Converter on the Operating Conditions. T. Lütgen. (Mitteilungen der Kohle- und Eisenforschung G.m.b.H., 1937, vol. 1, Apr., pp. 157–170). The author presents a study of the two most important factors in the basic Bessemer process, namely, the internal volume of the converter and the blowing period, their mutual influence on one another and in relation to the chemical and physical condition of the pig iron. He shows that if the pig-iron conditions are wrong, then an unsuitable shape of converter will make matters worse, while with a suitable shape of converter the influence of unsuitable pig-iron condition is decreased. He also considers both influences from the points of view of their effects on the deoxidation process and on the output from the rolling mill.

Slag Viscosity Control for Greater Uniformity in Steel. C. H. Herty, jun. (Iron Age, 1937, vol. 139, June 17, pp. 46–50). **Slag Viscosity Control Affords Greater Uniformity in Steel.** C. H. Herty, jun. (Steel, 1937, vol. 100, June 7, pp. 60–64, 90). The author points out the importance of controlling the slag in basic open-hearth practice, and gives brief particulars of an instrument known as Vis-Control for measuring slag viscosity. The use of this instrument enables the iron oxide in the slag to be held within narrow limits.

Influence of the Course of the Acid Open-Hearth Process on the Content of Non-Metallic Inclusions in the Steel. P. N. Iwanow, S. P. Samotajew and E. A. Morosowa. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 501–504). The authors present the results of an investigation of the influence of the working details, such as the course of melting, the duration of the heat, teeming methods, &c., of the acid open-hearth process on the amount of non-metallic inclusions found in the resulting steel produced. They show that in order that the steel may be as free from non-metallic inclusions as possible, attention must be given to the following points: (*a*) After melting down, the bath should contain 0·80–0·85% of carbon and not less than 0·35–0·45% of manganese. (*b*) The boil should last about 2–2¼ hr. (*c*) The carbon should be oxidised at a rate of about 0·23–0·27% per hr. (*d*) The ore addition during the boil should amount to 1·8–2·2%. (*e*) The amount of ferro-manganese used should lie between 50 and 100 kg. (*f*) The metal should stand in the ladle for not less than 15 min.

Basic Open-Hearth Slag Control. E. Cook. (Transactions of the American Society for Metals, 1937, vol. 25, pp. 325–419). The author presents a résumé of published information on open-hearth slags, and describes an investigation, carried out during the

past ten years, on the control of basic open-hearth slags. The physical chemistry of the process is discussed in detail. The production and characteristics of rimming steels are dealt with, and applications of variable deoxidation practices to maintain rimming qualities are suggested. The author emphasies the importance of the phosphorus and manganese contents of the blast-furnace burden in controlling open-hearth practice and costs.

Losses of Different Elements by Oxidation during the Melting of Iron in Induction Crucible Furnaces. V. M. Maltsev. (Katshestvennaia Stal, 1936, No. 8–9, pp. 47–52). The loss in weight of the metal by oxidation during the melting of steel in a crucible furnace was found to be about 1·5%. The highest losses were those of manganese, silicon, vanadium and carbon. The paper also contains data concerning the heat balance of the same furnace. (In Russian).

The Influence of the Arc Voltage on the Operation of the Electric Steel Furnace. F. K. Buchholz, A. Ziegler, and E. Voos. (Stahl und Eisen, 1937, vol. 57, June 17, pp. 681–682). The investigation of the heavy wear on the roof of an 8-ton Héroult three-phase arc furnace brought to light the fact that the electrical part of the furnace was out of order. The leads from the transformer to the electrodes were very long in comparison with modern construction; further, one lead was much longer than the other two, which were not of equal lengths. It was thought that the arc voltages must differ, owing to the different resistances of the leads; the arcs were observed to be very short, and, particularly during refining, the electrodes dipped partly into the slag. On the basis of measurements of the electrical characteristics of the leads and the electrode voltages, the transformer was moved closer to the furnace and the leads were rearranged. As a result the difference between the voltages of the electrodes was decreased, the power factor was raised, the roof wore more regularly and the electrodes no longer dipped into the slag. These observations were confirmed by a comparison of the electrode consumption before and after the reconstruction.

Influence on the Current Consumption of the Thermal Insulation of the Hearth in Arc Electric Steel Furnaces. H. Weitzer. (Stahl und Eisen, 1937, vol. 57, June 24, pp. 697–701). The author describes and discusses investigations made on the efficiency of melting of arc electric steel furnaces and the causes and extent of electrical losses. He then gives consideration to the heat insulation of the hearth from radiation and conduction losses; by this means the current consumption was reduced by 3% and the melting period by 11%, while the lining costs were also cut down.

Viewpoints of the Production of Electrodes from Coal Mixtures. H. Mönnig. (Glückauf, 1937, vol. 73. Apr. 17, pp. 359–361). The author describes the production of electrodes with particular reference to the use of mixtures of various coals as the raw material. Some suitable mixtures of various types of coals are listed.

Experimental Study of the Chemical Heterogeneity of Ingots. Application to an Iron-Nickel-Chromium-Carbon Alloy. P. Chevenard and A. Portevin. (Annales de l'Académie des Sciences Techniques à Varsovie, 1936, vol. 3, pp. 1–16). The authors present a study of the chemical heterogeneity of an alloy steel containing carbon 0·33%, nickel 37·05%, chromium 11·2%, manganese 1·85% and silicon 0·13%. The data recorded are apparently the same as those contained in a paper by Chevenard and Waché (*see* Journ. I. and S.I., 1936, No. II., p. 267 A).

The Formation of Inclusions in Steel. H. Wentrup. (Technische Mitteilungen Krupp, 1937, vol. 5, June (second number), pp. 131–152). After discussing the concept "inclusion," the author deals with the formation of oxide and sulphide inclusions in steel, making reference to the equilibrium diagrams of the following systems: Fe–Fe_2O_3, Fe–FeS, Fe–FeO–FeS, Fe–C–O, Fe–Mn–O, Fe–Mn–S, Fe–Mn–S–O, Fe–Si–O, Fe–Mn–Si–O and Fe–Al–O. Further, he reviews present knowledge of the system Fe–Si–Mn–Al–O. In conclusion he gives consideration to the formation of inclusions by external agencies, such as the air, refractory material from the furnace, and slag accompanying the steel.

REHEATING FURNACES

(Continued from p. 70 A)

Furnace-Charging and Ingot-Handling Machines. (Engineering, 1937, vol. 143, May 21, pp. 577–578). Illustrated particulars are given of a series of machines of German design, for furnace-charging and the handling of ingots and forgings.

Progress in Handling Large Forging Billets. A. J. G. Smith. (Heat Treating and Forging, 1937, vol. 23, Apr., pp. 178–179). Brief illustrated particulars are given of several types of manipulators and charging machines for the handling of billets and ingots during forging.

Tubular Recuperators Applied to Continuous Reheating Furnaces. W. H. Fitch. (Iron and Steel Engineer, 1937, vol. 14, Apr., pp. 17–29). The author describes the characteristics of the Carbofrax (silicon carbide) tubular recuperator, and gives illustrated particulars of several recuperator arrangements which have been adopted for continuous reheating furnaces in operation in American plants.

The Duration of Heating in the Rolling-Mill Furnace and its Influence on the Output. W. Kalkhof. (Stahl und Eisen, 1937, vol. 57, May 6, pp. 523–524). The author describes an investigation of the influence of the duration of reheating on the output of a rolling-mill, in which 35 ingots from one heat were treated exactly alike from their arrival at the mill till the rolled product reached the straightening machine, the only variable being the length of the reheating period, which varied between $4\frac{3}{4}$ and $9\frac{3}{4}$ hr.; the output was then examined from the point of view of quantity, quality and cost. The results are presented graphically and are discussed briefly.

Decarburisation in the Furnaces in the Rolling Plant. G. L. Livschitz and L. D. Kossovsky. (Katshestvennaia Stal, 1936, No. 8–9, pp. 55–56). Decarburisation begins at 700° to 750°; its extent depends essentially on the interval of heating in the 700° to 1100° C. zone and on the time during which the material remains in the zone of highest temperature. Temperatures above 1100° C. should not be used. (In Russian).

Two New Applications of Induction Heating. E. T. Cone. (Metals and Alloys, 1937, vol. 8, May, pp. 149–150). Illustrated particulars are given of the use of induction coils for the heating of tube ends prior to forging and swaging.

FORGING, STAMPING AND DRAWING

(Continued from p. 71 A)

The Unterloibl Hammer Forge. L. Jahne. (Montanistische Rundschau, 1937, vol. 29, July 1, pp. 1–4). The history of this works, situated near the Austria-Jugoslavia frontier, is related. It now forms part of the Kärntner Stahl- und Eisenwerke.

Three Decades of Development in Drop Forging Hammers. M. S. Reed. (Steel, 1937, vol. 100, June 7, pp. 46–49). The author summarises developments that have taken place in the past 30 years in the design of drop forging hammers.

Forging and Finishing Steel Knives. F. B. Jacobs. (Steel, 1937, vol. 100, June 14, pp. 40–42). An account is given of the principal operations involved in the manufacture of table knives.

Diagnosis of Metal Troubles in Industry. Part I. Forging. J. L. Burns and V. Brown. (Metal Progress, 1937, vol. 31, Apr., pp. 380–385). Illustrations are given of typical defects met with in forging practice due to improper die design, excessive heating and other causes.

Republics New Wire Mill includes Electro-Galvanising Equipment. (Iron Age, 1937, vol. 139, May 13, pp. 48–52, 146). Illustrated particulars are given of the equipment and methods used by the Republic Steel Corporation at their South Chicago Works for the electro-galvanising of steel wire.

ROLLING-MILL PRACTICE

(Continued from pp. 72 A–74 A)

Problems in the Field of Shaping. H. Sedlaczek. (Stahl und Eisen, 1937, vol. 57, June 24, pp. 702–704). The author presents a review of some of the problems to be solved in the shaping of materials by rolling.

Determination of Change-Over Time and Output of Rolling-Mill Trains with Frequent Changes of Product. M. Förster. (Stahl und Eisen, 1937, vol. 57, May 20, pp. 584–585). The author presents a study of the time consumed in readjusting or changing the rolls in a mill to suit the different types of product required, particularly where frequent changes are necessary, and its influence on the output of the mill.

Roll Designing for Section Steel. C. Holzweiler and T. Dahl. (Stahl und Eisen, 1937, vol. 57, June 3, pp. 625–632). The continuation of previous articles (*see* Journ. I. and S.I., 1937, No. I., p. 126 A). The authors discuss the differing play of forces on the various parts of the section in the rolling of **I**-sections; they recommend the replacement of the concepts direct pressure and indirect pressure by what they really represent, namely, the decrease of height and of width in the pass. They then discuss the judging of the suitability of the design of a series of passes by consideration of the ratios of the total area of the section before and after the pass applicable to the various passes; the individual parts of the section must be considered separately, however, and here the difficulty of delimiting the various parts arises. This problem can be solved graphically, however. Equations to represent the changes of the individual pass dimensions, which are generally applicable in the designing of **I**-passes, are developed. Graphical representation of the pass dimensions in relation to the pass number gives valuable information regarding the degree and uniformity of the stresses applied to the material and the mill plant in the individual passes, and indicates where adjustment may be required.

Sleeve Rolls. W. Trinks. (Blast Furnace and Steel Plant, 1937, vol. 25, May, pp. 496–498). It is pointed out that for the backing-up rolls in four-high mills one-piece cast-steel rolls cannot be produced to withstand the concentrated loads experienced for any length of time before spalling sets in. Sleeve rolls of proper material carefully made last much longer. The author discusses the thickness of the sleeves and the allowance to be made for shrinking or forcing on in the production of rolls of this type.

Experiences with Roller Bearings in Rolling-Mill and Pinion Housings. C. Fläschel. (Stahl und Eisen, 1937, vol. 57, June 17, pp. 673–680). At the Neunkircher Eisenwerk roller bearings have

been fitted in the last housings of the finishing mill for rolling wire-rod, bar and strip steel, and also in various pinion housings. The author explains the reasons leading up to this decision, and describes with diagrams the various types of roller bearings that were used. He then gives some information regarding the effects of the change-over to roller bearings from the previously used frictional types, and discusses the merits and demerits of the two kinds of bearings.

Efficiency and Design of Up-to-Date Pinion Housings. (Demag News, 1937, vol. 11, C. Apr., pp. 7–11). Illustrated particulars are given of modern types of pinion housings for rolling mills. The results of load tests of pinion housings are shown diagrammatically.

Extension of a Small-Section Rolling Mill to Cope with a Bigger Rolling Programme and Increased Output. (Demag News, 1937, vol. 11, C. Apr., pp. 1–7). The layout and equipment of a reconstructed section and wire-rod mill of German design are illustrated and described.

Production and Quality Control of Automobile Body Sheets. T. F. Olt. (American Society of Mechanical Engineers, June, 1937 : Iron Age, 1937, vol. 139, June 3, pp. 50–53, 122–126). The author outlines the four methods of cold-rolling sheets of deep-drawing quality with particular reference to the methods adopted at the plant of the American Rolling Mill Co. The various factors to be considered in the production of sheets of satisfactory quality are discussed.

Rolling and Sticking of Thin Sheets. E. Günther. (Stahl und Eisen, 1937, vol. 57, May 27, pp. 601–604). For the rolling-out of very thin sheets a mild degree of sticking is necessary. Under certain conditions and with certain material the sticking must be developed artificially by the application of high temperature and heavy pressure, *i.e.*, the material must first be made capable of sticking. The ability to stick depends on the sheet thickness, decreasing with increasing thickness owing to the greater stiffness of the sheet. With regard to the undesirable sticking experienced during the separation of the sheets, both the magnitude and the nature (whether uniform or not) of the pressure are of importance. The rolling pressure can be regulated in various ways, and is primarily dependent on the shape of the roll-body. By an experiment, the influence of non-uniform pressure on the flow phenomena in the sheet is shown, and the effect of the compressive action of the rolls, and of the time during which the material is subjected to the pressure of the rolls, on the sticking is explained.

Hot and Cold Strip Mills : Granite City Steel Co. H. Niedringhaus. (Iron and Steel Engineer, 1937, vol. 14, May, pp. 38–41). The layout and equipment of the strip mills of the Granite City Steel Co. are described and illustrated. (*See* Journ. I. and S.I., 1937, No. I., p. 268 A).

The Continuous Rolling of Hot Strip Steel. A. F. Giese, jun. (Iron and Steel Engineer, 1937, vol. 14, May, pp. 1–16). The author

discusses in some detail rolling-mill practice for the production of strip steel. Heating-furnace practice, the set-up of the rolls, the approximate drafts used, the speed of rolling and the temperature of the strip during its passage through the mills are dealt with.

The Production of Weldless Iron and Steel Tubes and the Phenomena during Skew Rolling. H. Schmid. (Montanistische Rundschau, 1937, vol. 29, May 1, pp. 1–8; May 16, pp. 1–8; June 1, pp. 1–12). After touching on the output of weldless tubes, the author gives a brief explanation of the basic principles of the various types of skew rolling mills, and then goes on to the design of the rolls or cones employed. Finally he describes the forces set up within the metal as a result of the action of the mill rolls or discs in the various forms of skew-rolling processes.

The Application of Nomography in Tube Rolling Mills. R. Mooshake. (Stahl und Eisen, 1937, vol. 57, June 10, pp. 649–655). The author describes the use of nomograms for calculating the weights and dimensions of the ingots, the lengths of the pierced billets and the dimensions of the Pilger rolls for rolling tubes. For this purpose four-scale nomograms are used, which are easy to read because the principal scales can be made linear. Examples are given of the use of these nomograms.

Ward-Leonard Control for Blooming and Slabbing Mill Auxiliaries. W. B. Snyder. (Iron and Steel Engineer, 1937, vol. 14, May, pp. 30–34). The author describes the Ward-Leonard control system for operating the screwdowns, side guards, live tables, and shear of a slabbing mill at the plant of the Inland Steel Co.

HEAT TREATMENT

(Continued from pp. 75 A–76 A)

Decarburisation of Tool Steel at High Temperatures. N. Gudzov and N. Vjasnikov. (Metallurgist, Russia, 1936, No. 2, pp. 26–35). The authors have investigated the decarburisation of tool steel and find that the temperature of the commencement of decarburisation increases with increasing carbon content. The boundary between the decarburised surface layer and the unchanged core becomes sharper at higher temperatures of decarburisation. The greater the quantity of surplus carbides in the steel, the slower is the decarburisation. Chromium prevents decarburisation. (In Russian).

Heat Treating Furnace Specifications. N. C. Bye. (Iron and Steel Engineer, 1937, vol. 14, May, pp. 27–29). The author discusses the design of a car-type annealing furnace, with special reference to temperature uniformity.

Heat Treatment of Structural Steel. Loxley. (Metallurgia, 1937, vol. 15, Apr., pp. 179–181; vol. 16, May, pp. 12–14). The author presents some general observations and some practical points on the heat treatment of structural steel.

Brunorised Rails Have Exceptional Properties. (Blast Furnace and Steel Plant, 1937, vol. 25, Apr., pp. 385–387). At the Gary plant of the Carnegie-Illinois Steel Corp. rails are given a heat treatment which is known as Brunorising. The rails from the mill are cooled to a temperature of between 900° and 1100° F. on the cooling beds and are then transferred to a gas-fired reheating furnace. This is 9 ft. 6 in. in width and 252 ft. long, and when fully charged holds six groups of eight 39-ft. rails. The rails, lying on their sides, are carried lengthwise through the furnace on rollers. The reheating time varies between 18 and 30 min., and new groups of rails are charged at uniform intervals of from 3 to 5 min. In the interval between charges, the rails in the furnace are moved backwards and forwards through a distance of 2 ft. by the constant oscillation of the rollers. The furnace is divided into eight zones for automatic heat control and is equipped with fans for gas circulation. The rails are uniformly heated during their travel through the first half of the furnace; the last half of the furnace is available for the thorough equalisation of heat. While the rails so treated may be slightly less hard and have a slightly lower tensile strength, this is more than offset by the improved ductility and toughness brought about by the fine grain structure

The Heat Treatment of Upholstery Springs. (Wire Industry, 1937, vol. 4, Apr., pp. 181–182). A short account is given of practice for the heat treatment of tension and compression springs used in the upholstery industry.

Quantity and Composition of the Gases in the Annealing of Steel for Dynamos. G. M. Korovin. (Katshestvennaia Stal, 1936, No. 8–9, pp. 36–37). Analytical investigations indicate a strong burning-out of the carbon during the annealing of unpickled (scale-covered) steel sheets. This causes an improvement in the magnetic properties (decrease in magnetic losses) as compared with similarly treated but pickled sheets of the same material. (In Russian).

Continuous Normalising Furnaces for Thin Sheets. (Iron and Coal Trades Review, 1937, vol. 134, June 25, pp. 1137–1138). An abridged English translation of a report by F. Lüth describing developments in the design and operation of normalising furnaces for sheets. The original report appeared in Stahl und Eisen, 1937, vol. 57, Apr. 8, pp. 365–372.

Austempering. E. S. Davenport. (Heat Treating and Forging, 1937, vol. 23, Apr., pp. 170–173, 177). The author describes the heat treatment of steel by direct transformation of the austenite. (*See* p. 76 A).

WELDING AND CUTTING

(Continued from pp. 77 A–79 A)

Notes on the Welding of Grey Iron Castings. W. Herrmann. (Welding Industry, 1937, vol. 5, May, pp. 124–127). A discussion of factors to be observed in the successful welding of iron castings.

The Use of Welding Rods which give an Austenitic Structure for the Welding of Plain and Low-Alloy (Non-Austenitic) Steels. K. L. Zeyen. (Technische Mitteilungen Krupp, 1937, vol. 5, June, pp. 89–102). The author presents a general survey of the welding of non-austenitic steels with austenitic welding rods. Examples are given to show the wide range of applicability and the special advantages of this method of welding; it is shown that in order to avoid defects certain welding conditions must be observed.

Arc Welding of Rustless Bimetals. G. M. Tichodejew. (Special Steel (Russia), 1936, vol. 45: Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, May 15, p. 579). The author has investigated the arc-welding of thin bimetallic sheets, 1·5 mm. thick, consisting of a sheet of stainless steel, 0·3 mm. thick, applied to a basis of plain steel; the edges were bent in various ways before welding. The strength properties and structures of the welds were determined. The author concludes that good welds can be made on such material with metallic electrodes such as are used for welding chromium-nickel steels. Of the various shapes given to the edges, bending each sheet back on itself gave the best results, the weld being made on the rustless-steel side.

Inspection of Welded Pressure Vessels. E. R. Fish. (Welding Journal, 1937, vol. 16, May, pp. 4–5). A brief discussion of shop and field inspection of welded pressure vessels.

Safety in Welding. R. B. Lincoln. (Welding Journal, 1937, vol. 16, May, pp. 6–10). The author discusses provisions that should be incorporated into specifications to ensure the production of perfect welds.

Stress Distribution in Fillet Welds—a Review of the Literature to January 1, 1937. A. G. Solakian and G. E. Claussen. (Welding Journal, 1937, vol. 16, May, Supplement). A review of the work of various investigators on stress distribution and its determination in fillet welds.

The Problem of the Weld Sensitiveness of Aircraft Structural Steels. F. Bollenrath and H. Cornelius. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, June, pp. 563–573). Comparative tests on the welding of fixed specimens, using three methods of clamping, gave practically identical results. For acceptance testing the clamped welded specimen is not adequate, as the results obtained by different testers are too irregular. If the welding is properly

carried out the tendency to fissure at welded junctions is less than when welding the same tubes in the clamping device. Left-hand and right-hand welding were found to be of equal value, but arcatom welding was superior to gas welding. The mode of effecting the melting has a marked influence on the weld-cracking; the filler material probably has some effect. The authors' tests indicate that sulphur contents up to 0·02% and phosphorus up to 0·025% are permissible in chromium-molybdenum steels. No connection between the oxygen, nitrogen or hydrogen content and the weld sensitiveness was observed. The influence of heat treatment before welding was not marked. The fluctuating tensile fatigue strength is much reduced by weld cracks.

The Fatigue Strength of Butt-Welded Joints, of Specimens with Laid-on Seams and of Strapped Joints. F. Kaufmann. (Technische Mitteilungen Krupp, 1937, vol. 5, June, pp. 102–125). The author first describes the testing machines used and their calibration, and the materials used. The analysis, metallographic features and static and dynamic strength properties of the structural steel St 37, and the composition as delivered and the strength properties after melting of the Zeus Special E (E 37, uncoated) electrode, the austenitic electrode (heavily coated) and the heavily-coated non-austenitic electrode (E 52 h) used in making the arc welds, are recorded. The fluctuating-stress fatique strength was determined for specimens with laid-on seams; the seams were laid on both longitudinally and across, and in some cases on one side, in others on both sides. In comparison with unaffected structural steel St 37, there was a reduction of fatigue strength of 42–50%; this was found to be due to a "shape effect," the stresses and notch effects, which influence the dynamic properties of the basis metal. The fatigue strength of V-welded butt joints with the weld (*a*) across, (*b*) at 45° to, and (*c*) parallel to the direction of loading, was determined. Here, the type of electrode had no effect. Attempts to improve the strength by treatment of the weld were fruitless. The results obtained in the foregoing tests were used in the development of a new type of strapped joint; the artificially induced self-stresses set up by the suitable application of additional weld seams lead to a considerable increase in the fluctuating-stress fatigue strength.

CLEANING AND PICKLING OF METALS

(Continued from p. 23 A)

Cleaning Before Plating. F. A. Maurer. (American Electroplaters Society: Metal Industry, 1937, vol. 50, June 4, pp. 633–635). The author surveys and classifies methods of cleaning metals before electrodeposition.

Some Scientific Aspects of the Problem of the Pickling of Ferrous Metals. E. Herzog. (Métaux et Corrosion, 1937, vol. 12, Mar., pp. 52–58). The author discusses the nature, physical and chemical, of the oxides to be removed from steel by pickling, processes of removing them (*a*) mechanically, (*b*) chemically, and the theory of the action of inhibitors, (*a*) salts of arsenic and antimony, (*b*) organic compounds. In an appendix he touches very briefly on electrolytic pickling, brittleness due to hydrogen, and the oxides in the scale on steel.

The Pickling of Steel. T. P. Hoar. (Newport Metallurgical Society: Iron and Steel Industry, 1937, vol. 10, Apr., pp. 340–344). A brief account is given of recent research work on the pickling process. The mechanism of pickling, pickling defects, inhibitors, and electrolytic pickling are dealt with.

Modern White Pickling Plant for a Tinplate Rolling Mill. (Demag News, 1937, vol. 11, C. Apr., pp. 11–12). Illustrated particulars are given of a pickling plant using compressed air as the driving medium. In this plant the spent air after passing through a low-pressure air receiver is recompressed in the circuit to the required working pressure.

The Problem of Pickling Tanks for the Pickling of Tubes. Schmiedt-Steding. (Internationale Röhrenindustrie, 1937, vol. 2, June, pp. 5–7). The author discusses the materials used for the construction of pickling tanks.

Steel Pickle-Brittleness. R. Saxton. (Metallurgia, 1937, vol. 16, pp. 23–24). A brief discussion of the brittleness of steel due to pickling.

Modern Fume and Acid Sewer Serves Continuous Strip Pickling Unit. J. R. Hoover. (Steel, 1937, vol. 100, Mar. 29, pp. 71–72). Illustrated particulars are given of the constructional arrangement of the sewer designed for the direct handling of the acid, water and fumes discharged from the pickling tanks in operation at the plant of the Youngstown Sheet and Tube Co., Campbell, Ohio.

Rubber Lined Steel Sewer Pipe Handling Acid Waste. H. C. Klein. (Iron Age, 1937, vol. 139, Apr. 1, pp. 44–46). Brief particulars are given of the application of rubber-lined steel pipes in pickling plants for the disposal of waste liquor.

COATING OF METALS

(Continued from pp. 24 A–30 A)

Magnetic Method for Measuring the Thickness of Nickel Coatings on Nonmagnetic Base Metals. A. Brenner. (Journal of Research of the National Bureau of Standards, 1937, vol. 18, May, pp. 565–583). The local thickness of an electroplated nickel coating on a nonmagnetic base metal may be measured by the force of attraction of a small permanent magnet, the attractive force being determined with a simple spring balance. It was found that the attractive force between the magnet and coating is proportional to the thickness of the coating. The instrument is calibrated with nickel coatings of known thickness which have been deposited under about the same conditions as the coatings to be tested. Nickel coatings deposited under different conditions have somewhat different magnetic properties, which become uniform by heating the samples to 400° C. (750° F.). Specimens of unknown history should be annealed before testing. Measurements on coatings as deposited are correct within $\pm$ 15% and on annealed coatings within $\pm$ 10°. The effect on magnetic measurements of factors such as curvature of the surface, type of base metal, and superposed chromium coatings is discussed. The magnetic method was shown to be applicable to the testing of nickel-plated brass plumbing fixtures.

Rapid Electrodeposition of Iron from Ferrous Chloride Baths. C. Kasper. (Journal of Research of the National Bureau of Standards, 137, vol. 18, May, pp. 535–541). Ductile iron can be deposited from ferrous chloride solutions at current densities up to 30 amp./per sq. dm. (280 amp./per sq. ft.), which is several times the customary rate of iron deposition. The temperature and acidity of the baths must be controlled within narrow limits.

Organic Contaminants in Nickel Baths. A. W. Hothersall and G. E. Gardam. (Electrodepositors' Technical Society: Metal Industry, 1937, vol. 50, May 28, pp. 609–612). The influence of certain typical organic materials in nickel depositing solutions on the properties of the deposits and the comparative effectiveness of a number of methods of purification are described.

Rust Proofing Process Involves Electrodeposition of Metal Alloy. (Steel, 1937, vol. 100, June 14, pp. 64–66). Reference is made to a rust-proofing process which involves the electrodeposition of a special metal known as Oxoseal alloy. No particulars are given of the method of carrying out the process or the composition of the alloy used.

Electrodeposited Lead for the Protection of Iron and Steel. F. W. Hay. (Metallurgist, 1937, vol. 11, Apr. 30, p. 23). An effective and permanent protection of structural parts can be obtained by an

electrolytic coating of lead. The lead film formed is a continuous layer, which is firmly amalgamated with the surface of the iron, so that it cannot be detached, and since lead is capable of withstanding corrosive gases, fumes, &c., any corrosion of the iron by fumes is avoided. The electrolytic deposition of lead is carried out in the cold, and can be so adjusted that the coating of lead obtained varies in thickness from 0·02 mm. to 3 mm., and over, according to the degree of protection required. Any deformation of the original material by heating, is, of course, out of the question.

The Homogeneous Lead-Coating of Steel Tubes. K. zur Heyden. (Internationale Röhrenindustrie, 1937, vol. 2, May, pp. 4–6). The author reviews the conditions imposed on the lead coatings of tubes and containers in the plant employed in the chemical industry, and then discusses the preparation of the surface of the steel and the application of the lead coating. The coating of lead on steel is troublesome, in that these elements do not form a solid solution, so that the production of an adherent coating is difficult.

Metals Co-deposited with Tungsten from the Alkaline Tungsten Plating Bath. M. L. Holt. (Electrochemical Society, Apr., 1937, Preprint No. 71–30). This study of the effect of various metal salts added to the Fink tungsten plating bath is a continuation of previous work. Plating baths which were made of specially purified materials gave no deposit when used in the ordinary electrolysis. Fink recommended certain metal additions to the bath to act as depolarisers. Some of the metal salts added acted as depolarisers and co-deposited with tungsten at the cathode. Various compounds of iron, except potassium ferri- and ferrocyanide, were equally effective. The nickel compounds tried showed no outstanding differences. Cobalt, tin, and cadmium were found to co-deposit with tungsten. It seems likely that the position of the metal in the electrochemical series determines whether or not it acts as a depolariser.

Diffusion Through Ferrous Welds of Duo Clad Metals. L. C. Grimshaw. (Metal Progress, 1937, vol. 31, May, pp. 504–507). In the Armstrong process for the production of composite steel billets by forging or rolling, the bond between the two metals comprising the billet is formed by electrolytic iron deposited on the surfaces to be welded. Using specimens of Armstrong composite metal the author has studied the diffusion of carbon from one type of steel to another. It is shown that the composition of the steel affects the carbide diffusion, and that carbon apparently diffuses faster from high-speed steel containing cobalt and molybdenum than from plain high-speed steel.

Nickel and Zinc Electroplate Finishes for Iron and Steel Components. E. E. Halls. (Metallurgia, 1937, vol. 16, May, pp. 9–11). The author points out the improvement effected in the quality and durability of electro-plated zinc coatings by a preliminary coating of nickel. The results of comparative accelerated corrosion tests on

direct zinc coatings and nickel-zinc coatings shows the improved durability of the latter.

Electro-Galvanising Round Wire with Heavy Coatings—A Recent Development. C. C. Crane. (Steel, 1937, vol. 100, May 10, pp. 71–72). Brief particulars are given of the electro-galvanising process in operation at the plant of the Republic Steel Corporation, South Chicago, Illinois. It is stated that with the galvanising solution used it is possible to deposit on round wire uniform and brilliant coatings at current densities up to 1500 amp. per sq. ft.

Ductile Zinc Coating Deposited on Wire by Electrolysis. E. E. Thum. (Metal Progress, 1937, vol. 31, May, pp. 524–528, 544). The author describes the practice of the Bethlehem Steel Co. for the electro-galvanising of steel wire. The method employed is known as the Bethanising process.

Galvanised Sheets and Galvannealed Sheets. J. L. Schueler. (Metal Progress, 1937, vol. 31, May, pp. 499–503). The sheet galvannealing process is identical with the sheet galvanising process up to the point where the sheet leaves the zinc pot. Then, instead of being allowed to cool, as in the galvanising process, the coated sheet is passed into a heat-treatment furnace where it is subjected to a temperature of 650° C., or higher, depending on the gauge of the sheet, the weight of the coating, the speed of travel and the length of the furnace. The sheets are then cooled in air. This heat treatment prevents the formation of spangles on the sheet and produces a silver-grey matte surface. It also causes the coating, if normally heavy and brittle, to become more malleable and, to some extent, causes a redistribution of the zinc to form a coating of more uniform structure.

The Methods of Testing Zinc Coatings. L. Kenworthy. (Journal of the Institute of Metals, 1937, vol. 61) (Advance copy). The measurement of the protective value of zinc coatings on iron and steel, other than by accelerated corrosion tests, is carried out by examination of certain properties of the coating—namely, average weight, uniformity, structure, and porosity. Under these four headings, the various methods which are in use or which have been proposed for carrying out this type of determination are described, together with their respective advantages, limitations, and in certain cases suggested modifications. Methods for determining the average weight mostly depend on direct weighing of the sample before and after the coating has been removed. Other methods make use of the heat developed or the gas evolved during the dissolution of the coating in acid. In the recently developed electrolytic test (Britton's test) the time taken to remove the coating with a known current density is used. Chemical methods of dissolution, depending on a time factor for the determination of the thickness, are not applicable to coatings partially or entirely composed of alloy layer, because of variation in the rate of dissolution with composition. They may be suitable, however, for the measurement of uniformity, as is the

case with the copper sulphate (Preece) test. The electrolytic test, on the other hand, removes the same weight of coating per unit time irrespective of composition. The structure is preferably determined by metallographic examination, while the weight of the component layers of the coating may be measured by the electrolytic test using potential measurements. Several proposed tests for porosity are described, although this property does not assume for zinc coatings the same importance as for coatings electropositive to iron. The requirements of zinc coatings to withstand corrosion vary with the conditions of exposure, and while for atmospheric attack the life is almost entirely dependent on the total weight of the coating (including alloy layer), for immersed conditions there is evidence that the composition of the coating plays an important part. The particular advantages of certain methods for evaluating the various requirements for both types of conditions are discussed.

Protective Metallic Coatings by the Wire Spraying Process. H. J. Williams. (Journal of the Institution of Production Engineers, 1937, vol. 16, Mar., pp. 251–266). The author outlines the wire method of metal spraying and discusses its possibilities.

A Critical Analysis of some Statements and Experiments on the Adherence of Sheet-Steel Ground Coats. J. O. Lord. (Journal of the American Ceramic Society, 1937, vol. 20, Apr., pp. 111–114). The author reviews and discusses the published information on developments in the study of enamel adherence.

Cast-Iron Structure Changes during Firing Cycle of Vitreous Enamel. R. B. Schaal. (Steel, 1937, vol. 100, June 7, pp. 72–73, 90). Micrographs are given showing the structural changes undergone by cast iron during the vitreous enamelling process.

Paint Tests on Iron and Steel. J. C. Hudson. (Oil and Colour Chemists Association, Apr. 8, 1937 : Paint Manufacture, 1937, vol. 7, May, pp. 150–153). The author discusses three main aspects of paint testing : Experimental methods of conducting tests on paints applied to iron and steel, some of the major tests that have been made in this field, and possible subjects for future research. The paper is based on the work of the Corrosion Committee of the Iron and Steel Institute.

PROPERTIES AND TESTS

(Continued from pp. 81 A–92 A)

Surmountable and Insuperable Difficulties in Getting the True Value out of Metals. M. Verner. (Metallwirtschaft, 1937, vol. 16, June 4, pp. 545–550). The author discusses in a general way the difficulties that arise in the use of metals in getting the full value out of the material used; these difficulties may be due to several causes, such as defects in the metal, improper treatment of the material, or the choice of an unsuitable metal for the purpose in view—in the latter connection it sometimes happens that there is no known commercial metal which possesses all the properties desired.

The Definition of the " Class " of Steels. G. Charpy. (Académie des Sciences, May 10, 1937 : Génie Civil, 1937, vol. 111, July 3, p. 20). In French it is usual to refer to the " *nuance* " of a steel (the " class " to which it belongs) *i.e.*, hard, soft, &c. The author points out, however, that the properties of materials falling within a given class may vary very considerably, depending on the treatment applied during the steelmaking process and afterwards, and discusses the possibility of defining the conditions, both of the materials and of the testing procedure, for the testing of classes of steel so that the term class may take on a more definite significance.

A Study of the Effect of Span on the Transverse Test Results for Cast Iron. J. T. MacKenzie and C. K. Donoho. (American Society for Testing Materials, 1937, Preprint No. 31). The author investigates the variation in results of transverse tests of cast iron caused by varying spans. Tests by previous investigators are discussed, as well as methods and results of new tests on rectangular bars of two different types of grey iron. By mathematical analysis of the results, a quantitative measure of the effect of changing the span-to-depth ratio is developed for bars of both round and rectangular section.

An Empirical Formula to Find Tensile Strength of Cast Iron From Transverse Test Results. K. Isida. (Transactions of the Society of Mechanical Engineers, Japan, 1936, vol. 2, Nov., pp. 415–422). The author attempts to establish an empirical formula for determining the tensile strength of cast iron from the results obtained in transverse testing. (In Japanese).

Relation of Properties of Cast Iron to Thickness of Castings. H. L. Campbell. (American Society for Testing Materials, 1937, Preprint No. 30). Data are presented on the tensile and compressive strengths of irons cast in round bars of different diameters. The results of other investigations on this subject are reviewed. Experimental test data are summarised on a chart which indicates the relation of the tensile strength to the thickness of the metal in

separately-cast round bars. This characteristic of gray cast iron has special significance in the development of designs for iron castings.

The Stiffness or Flexure Test. H. L. MacBride. (American Society for Testing Materials, 1937, Preprint No. 36). The author discusses the test known as the cantilever bend, stiffness, or flexure test for light wire, sheet and strip of various materials. A description is given of a stiffness testing machine (the Tour-Marshall tester) and the method of testing is explained. Charts are shown of typical tests on different materials and a brief interpretation is given, with a comparison of stiffness test results with those given by other methods.

Value of the Simplified Impact Test for Measuring the Brittleness of Round Bars of Ordinary Steel. P. Dejean and P. Simard. (Génie Civil, 1937, vol. 110, June 19, pp. 542–544). The simplified impact test was described by Dejean and Gerszonowicz (*see* Journ. I. and S.I., 1936, No. II., p. 36 A). Originally it was specified that the " angle of fracture " of concrete reinforcement bars must exceed 20°; later it was decided to indicate the minimum value of the angle by the expression $40/\sqrt[3]{d}$, d being the diameter of the round bar, and finally this expression was replaced by $1000/(E\sqrt[3]{d})$, where E is the elastic limit of the bar. The authors have made tests on two basic Bessemer steels (0·13 and 0·25% of carbon) in the as-rolled condition, to test out the validity of the expressions suggested. In a summarising diagram they compare the experimental curves giving the angle of fracture as a function of the diameter with the curves derived from the application of the formula $1000/E\sqrt[3]{d}$; it appears that the conditions are too severe for small bars and not sufficiently severe for large ones. They suggest that this simplified test should be used under the following restrictions :—

Steel Type.					Angle of Fracture.
Tensile strength	$\leqslant$ 45 kg. per sq. mm.	.	.	$\geqslant 20°$
,,	,, 45–55 ,, ,,	.	.	$\geqslant 15°$
,,	,, 55–65 ,, ,,	.	.	$\geqslant 10°$

The authors point out that this specification should be applied only to as-rolled bars; there is a tendency to use cold-worked bars in reinforced concrete, and the conditions for acceptance of such bars must be studied specially. In conclusion, the authors add a note to show how deceptive the brittleness test can be if it is not applied discerningly.

High-Yield Resilient Tinplate. (Iron Age, 1937, vol. 139, June 10, pp. 51–53). A brief discussion of the improvement in properties effected by the cold-rolling of sheets intended for tinplate manufacture is given.

A Fatigue Machine for Testing Metals at Elevated Temperatures. F. M. Howell and E. S. Howarth. (American Society for Testing Materials, 1937, Preprint No. 39). The authors describe and

discuss in some detail a fatigue machine for testing metals at elevated temperatures. The specimen used is part of a cantilever beam, one end of which is fixed in an electrically heated furnace. While the specimen is entirely within the furnace, the deflected beam assembly extends outside the furnace wall and is revolved in a circle by a variable eccentric driven at 3600 r.p.m. A unique calibration apparatus is used to load the specimen and to measure the resulting deflection while the machine is in operation. From the load-deflection relationship thus obtained, the stress in the test specimen can be calculated. The method of temperature control is described. Specimen temperatures from room temperature up to 600° F. can be controlled within $\pm$ 2° F. Errors due to speed effect, misalignment, variation in specimen size and method of stress calculation are discussed. These errors indicate that the maximum stress in the specimen can be calculated within $\pm$ 3%. Calibration curves and results of fatigue tests on one of the commercial aluminium alloys, representative of the type of data obtainable, are included.

Rotary Endurance Bend Testing Machine with Hard Loading Spring. W. Späth. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, June 19, pp. 710–712). Theoretical considerations show that the results of a loading test depend not only on the specimen itself but also on the elastic properties of the testing apparatus used. Using the Schenck rotary endurance bend testing machine as an example, experiments showed that the load diagrams could be very considerably influenced by the mode of applying the load. The normal machine in use to-day with the load applied by weights gives very smooth curves, the commencement of plastic deformation being indicated only by a gradual change of direction of the curve; a modified machine, in which the load is applied by a hard spring, indicates small plastic deformations by a clearly observable decrease in the stress. With such a machine it is possible to probe more deeply into the finer details of the phenomena occurring in the loaded material. The results of tests made in this way on steel and aluminium are described; those obtained with steel demonstrate that the effect of notches can now be recognised in the load diagram. However, the question whether the observed stress decreases are unequivocally related to the fatigue strength cannot yet be answered, owing to the complexity of the problem.

Fatigue Testing of Wire. H. F. Moore. (Wire and Wire Products, 1937, vol. 12, May, pp. 235–236). Various types of machines for the fatigue testing of wire are briefly described and illustrated.

Fatigue Properties of Metals Used in Aircraft Construction at 3450 and 10,600 Cycles. T. T. Oberg and J. B. Johnson. (American Society for Testing Materials, 1937, Preprint No. 38). A description of a ball-bearing rotating-beam machine operating at 10,600 cycles and the results of comparative tests on these machines and ball-

bearing and plain-bearing machines operating at 3450 and 1725 r.p.m., respectively, are given. Plain and notched specimens were used. Operating temperatures are discussed. The values for the fatigue limits were not appreciably affected by this range of speed.

Yielding of Carbon Steel Specimens Subjected to Repeated Tensile Stresses. A. Ono. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 2, Nov., pp. 457–459). The author has carried out repeated-stress tensile tests on a number of carbon steels, in which the stress varied between a positive limit and zero. The yielding of the specimens was studied. (In Japanese).

Degree of Fatigue of Carbon Steels Under Repeated Bending. F. Oshiba. (Kinzoku no Kenkyu, 1937, vol. 14, Mar., pp. 96–106). The author has studied the progress of fatigue of carbon steels under repeated bending. (In Japanese).

Effect of Notches on the Endurance Limit of Steel. T. Nisihara and T. Sakurai. (Transactions of the Society of Mechanical Engineers, Japan, 1936, vol. 2, Nov., pp. 436–446). The authors have carried out repeated-stress tests on carbon steels and have studied the effects of notches, holes, and screw threads. (In Japanese).

Over-stressing and Under-stressing in Fatigue. J. B. Kommers. (Engineering, 1937, vol. 143, May 28, pp. 620–622; June 11, pp. 676–678). The author surveys previous work on the stressing of materials below and above the endurance limit, and describes his own investigation of the over-stressing of carbon steel. For the two carbon steels discussed, the usual effect of cyclic over-stress was to reduce the endurance limit. In some cases cyclic over-stress may produce small amounts of strengthening, but this is true only at very small cycle ratios and the smaller values of over-stress. The two important factors which determine the amount of damage due to over-stress seem to be the percentage of over-stress and the cycle ratio. The damage caused by cyclic over-stress seems to be a very gradual process, since the damage curves do not show any abrupt changes of slope. The damage curves, even for large cycle ratios, give no indication that an actual crack has been formed. Progressive cyclic under-stress, applied to a specimen subsequent to over-stress, may not only repair the damage which has been done, but in some cases may augment the original endurance limit by substantial percentages. In some cases the endurance limit may be restored to a value considerably above that of the original over-stress. Progressive cyclic under-stress may strengthen a material even after large cycle ratios of over-stress. The endurance limit of a material is not a fixed quantity. It may be manipulated by various stressing methods. Periods of cyclic over-stress will usually reduce the endurance limit, while periods of progressive cyclic under-stress may greatly increase the endurance limit.

Develops Hardening Machine for Double Helical Gears. (Iron Age, 1937, vol. 139, May 27, pp. 54–55). Illustrated particulars

are given of a torch hardening machine, especially suitable for the hardening of double helical gear teeth. The machine is designed on the Shorter principle.

Differing Readings of Rebound Hardness Testers. W. Hengemühle and E. Clauss. (Stahl und Eisen, 1937, vol. 57, June 10, pp. 657–660). The authors present the results of tests made on a number of hardness testers of the rebound type to determine the influence of the shape of the " point " and the weight of the striker, and of the height and velocity of its fall, on the height of rebound. The influence of the basis material on the readings obtained when testing surface-hardened parts was also investigated.

Static and Dynamic Hot Hardness of Steels. R. Walzel. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, June, pp. 577–580). Starting out from observations on the static and dynamic ball hardness of a series of steels at raised temperatures, the author puts forward considerations on the procedure with time of the hardening process during the ball hardness test. There are differences between the results of a dynamic test, a static test with the usual rate of loading and a static test with special slow loading, which, on repetition at other temperatures, change in part in the same sense, and in part in opposite directions. The author attempts to explain these results by means of two processes of hardening which take place with different degrees of ease and give rise to different increases of hardness. Finally, he presents a three-dimensional diagram in which the hardness increase due to hardening during the ball test is related to the duration and temperature of the test.

A Symposium on Wear of Metals. H. W. Gillett. (Metals and Alloys, 1937, vol. 8, May, pp. 123–125). A Symposium on the wear of metals was held at the Engineers' Club, Philadelphia, April 5, 1937, under the auspices of the Philadelphia District Committee of the American Society for Testing Materials. Abstracts of the papers are given.

The Effect of Surface Stress on the Wear of Metals. N. Sawin. (Machinery, 1937, vol. 50, May 6, pp. 165–167). The author gives brief particulars of the Skoda-Sawin machine for testing the wear of metals and discusses the effect of surface stresses on the wear of tool steel.

Steel for Transformers with Higher Permeability in the Direction of Rolling. A. S. Sajmovsky and L. S. Kasarnovsky. (Katshestvennaia Stal, 1936, No. 8–9, pp. 19–22). The authors have investigated the texture of transformer steel with 3·4% of silicon after cold-rolling and annealing. A single rolling and quenching treatment causes no appreciable orientation of the crystallographic axes. The same operation repeated twice causes the (100) axis to orientate in the direction of rolling, giving a marked increase in the permeability in this direction. (In Russian).

Nickel-free Magnetically Stable Alloys. W. S. Messkin and J. M. Margolin. (Katshestvennaia Stal, 1936, No. 8–9, pp. 23–30). The

authors have investigated the residual magnetic induction of different iron alloys, containing silicon, molybdenum, copper, phosphorus, nickel plus aluminium, manganese plus aluminium, and manganese plus aluminium plus chromium plus silicon plus copper. The residual induction decreases generally with increasing homogeneity (*i.e.* with the formation of solid solutions) and increases again with the dissociation of supersaturated solutions. It is possible to prepare iron alloys with low residual induction (*i.e.* high " magnetic stability "), coupled with low hysteresis losses, high electrical resistance and satisfactory mechanical properties without using nickel. Alloys of this kind may replace " isoperm " (nickel plus iron plus copper) for induction-coil cores. (In Russian).

Nickel-Iron Alloys of High Permeability, with Special Reference to Mumetal. W. F. Randall. (Journal of the Institution of Electrical Engineers, 1937, vol. 80, June, pp. 647–667). The author summarises the development of high-permeability alloys from early researches to the commercial products of the present day. The difficulties encountered during manufacture, and the precautions necessary in these metallurgical processes, are described. Stress is laid on the correct methods of application to ensure that the magnetic properties of the alloys are utilised to full advantage, and the need for heat treatment is emphasised. Propositions are put forward to explain the mechanism of this heat-treatment process, and the practical procedure is given. Data on curves show the electrical and magnetic properties of the alloys. The author finally discusses the practical applications of high-permeability materials, giving examples of commercial instruments and indicating cases in which their extended use would be advantageous.

Calculation of the Specific Heats and Entropies of Metal Vapours from Spectroscopic Data, with Special Reference to Gaseous Iron and Copper. K. K. Kelley. (United States Bureau of Mines, Report of Investigations No. 3341, May 1937). The method of calculating the specific heat and entropy from spectroscopic data, developed by W. F. Giauque, is applied to iron and copper vapours.

Preparation of Iron Oxide as a Source of High-Purity Iron. H. E. Cleaves and J. G. Thompson. (Journal of Research of the National Bureau of Standards, 1937, vol. 18, May, pp. 595–607). Selected ferric nitrate has been purified by recrystallisation, yielding several lots of iron oxide of high purity. Examination of the products by spectrochemical and chemical methods, for the presence of 51 possible impurities, shows that silicon is the principal impurity in each of the oxides; in the best materials the silicon content was 0·005 or 0·006%. Four additional elements, aluminium, calcium, magnesium, and copper are present, but the sum of these four is less than 0·001% in each sample. These oxides have been prepared as a preliminary step in the preparation of metallic iron of high purity.

A Study of Oxide Films on Metal Surfaces with Cathode Ray Diffraction. II.—Fe, Cr, Ni and Their Alloys. S. Miyake. (Scientific Papers of the Institute of Physical and Chemical Research, Japan, 1937, vol. 31, Mar., pp. 161–173). Part I. contained an account of the examination of oxide films formed at high temperatures on copper. The present paper is concerned with oxide films produced at high temperatures on iron, chromium, nickel and their important alloys, which were studied by means of cathode ray diffraction. On heating an iron surface to above 250° C., an α-Fe_2O_3 film was observed, but at lower temperatures (*e.g.*, 200° C.) Fe_3O_4 was presumably formed; the latter compound was also found in the underlying layer beneath the uppermost α-Fe_2O_3 film. NiO and Cr_2O_3 were observed on nickel and chromium surfaces, respectively. On the surfaces of iron-aluminium alloys (aluminium 2–15%) and iron-nickel alloys (nickel 3–36%) no oxides other than α-Fe_2O_3 were detected. Stainless steels gave rise to $FeCr_2O_4$ co-existing with Cr_2O_3 or a Cr_2O_3–Fe_2O_3 solid solution. A pure film of $NiCr_2O_4$ was formed on nichrome.

On the Oxidation of Iron and Cementite and Some Properties of Iron Oxides. K. Endo. (Science Reports of the Tôhoku Imperial University, 1937, vol. 25, pp. 879–920). The author has studied the oxidation of powdered specimens of iron, Fe_3C, Fe_2O_3, Fe_3O_4, and FeO during heating or cooling in air by means of a thermal balance, and chemical and X-ray analysis. The relation between the oxidation and the heating temperature, as observed in deoxidised iron and cementite, shows a stepped change in weight. This phenomenon in Fe_3C is probably due to the property of the contained carbon; it is concluded that the carbon in Fe_3C is lost from the structure, and the nascent iron atoms immediately combine with the oxygen that has diffused into it. Generally speaking, oxidation may be accompanied by a change of magnetisation at high temperatures. From the results of magnetic analysis, electrical resistance and thermal analysis, the conclusion is drawn that besides the well-known magnetic transformation at 680°, Fe_2O_3 has a new transformation at 1030°. According to the X-ray investigation, the diffraction patterns above and below 1030° are the same and are of the Al_2O_3 type. The ferromagnetic ferric oxide belongs to the same crystal type as Fe_3O_4, and may be considered to be γ-Fe_2O_3 containing oxygen. It may be assumed that the unit cell of the spinell type contains four molecules of surplus oxygen. On heating the specimen to 600°, its magnetisation rapidly decreases and the structure becomes mostly the Al_2O_3 type. The comparison, in point of their oxidation by heating, between ferromagnetic ferric oxide and natural magnetite, shows that the freshly diffused oxygen immediately combines with iron atoms and forms a crystal type; but the surplus oxygen which was previously contained in it is inactive. The change in limonite caused by heating was observed by the change of magnetisation,

X-ray analysis and the thermobalance. The crystal structure of limonite containing one molecule of water of crystallisation is not of the Al_2O_3 type, but takes this form by losing its water of crystallisation at 340°. The manganese contained in limonite as an impurity combines with iron oxide above 1000°, and forms $MnO.Fe_2O_3$, which is strongly magnetic at room temperature.

Air Furnace for Carrying out Creep Tests. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, June, pp. 555–562). In making creep tests the temperature must be kept constant not only during the entire test period but also over the whole length of the specimens; variations of more than $\pm$ 3° are not accepted to-day. For controlling the temperature during the test, various regulators are used. In order to equalise the temperature along the length of the specimen, salt baths have been used, but with them the specimens may be affected by the absorption of nitrogen and by corrosion, and air furnaces are being used to an increasing extent. In these furnaces the equalisation of the temperature along the specimen length is attained by heating the ends more strongly, by filling up the space previously occupied by the salt bath, and by preventing the flow of heat from the ends by shields. In this paper, which constitutes Report No. 378 of the Materials Committee of the Verein deutscher Eisenhüttenleute, eight types of air furnace are described by the following authors (the names in brackets indicate the places where the furnaces are in use): (1) F. Bollenrath, W. Bungardt and H. Cornelius (Deutsche Versuchsanstalt für Luftfahrt, e.V.). (2) H. Esser. (3) H. Kiessler (Deutsche Edelstahlwerke, A.-G.). (4) A. Krisch (Kaiser-Wilhelm-Institut für Eisenforschung). (5) K. Linden (Mannesmannröhren-Werke). (6) W. Marx (Losenhausenwerk, A.-G.). (7) R. Mailänder and W. Ruttmann (Fried. Krupp A.-G.). (8) H. Scholz (Forschungsinstitut der Kohle- und Eisenforschung, G.m.b.H.).

A Comparison of the Methods Used for Interpreting Creep Test Data. J. Marin. (American Society for Testing Materials, 1937, Preprint No. 42). A number of methods have been developed for interpreting tension creep test data for the purpose of determining working stresses. All methods require extrapolation of the test results beyond the times covered by the tests. Various procedures have been used in making such extrapolations. The author compares the working stress values as determined by the various methods. A comparison of the results shows that there are appreciable differences in the working stresses as obtained by different methods of interpretation.

Creep of Stainless Steels. S. I. Wolfson and A. M. Borsdyka. (Katshestvennaia Stal, 1936, No. 8–9, pp. 8–12). The authors investigated the mechanical properties of four stainless steels: (1) 12% chromium; (2) 3% silicon, 10% chromium (silchrome); (3) 5·8% nickel, 19% chromium; and (4) 8·9% manganese, 17% chromium, 2·2% tungsten. They measured the creep velocity at

400° to 600° C. for 140 hr. and made "instantaneous" tests of the limiting stress (for 0·2% and 0·01% elongation), the tensile strength, relative elongation and change of cross-section, from 20° to 700° C. "Instantaneous" tests indicated the same differences in mechanical properties as did the slow creep measurements. The strength of steels (1) and (2) decreased rapidly at 400° to 550° C.; parts made of these steels should not be submitted to mechanical stresses above 500° C. Steel (3), of the austenitic type, was less strong than steels (1) and (2) in the cold, but was by far the best at high temperatures, and can be used up to 700° C. Steel (4), specially prepared for this purpose, had a creep velocity of only one-half that of steel (3) and equalled, from this point of view, Krupp's WF100 steel (14% nickel and chromium, 2% tungsten). These results indicate the possibility of replacing nickel by manganese in the production of stainless steels with good mechanical properties at high temperatures. (In Russian).

Action of Hydrogen on Steel. P. Bardenheuer. (Stahl und Eisen, 1937, vol. 57, May 27, pp. 593–599). The author presents a survey of present-day knowledge on the effect of hydrogen in steel. In all cases, whether the hydrogen penetrates the steel during pickling or whether it be absorbed during reheating or melting, its adverse influence is due to the fact that it exists in the steel in the molecular form or as some gaseous hydrogen compound under high pressure, and can destroy the structural cohesion. Judging from experience, it is to be assumed that research in this field will throw light on material damage and the depreciation of mechanical properties for which hydrogen is responsible. It is to be stressed, therefore, that more attention should be given to the behaviour of hydrogen during both the manufacture of steel and its further treatment.

Copper Has Beneficial Effect on Cast Iron Properties. V. H. Schnee. (Foundry, 1937, vol. 65, May, pp. 39–40, 127–128). The physical properties of copper cast irons, copper-nickel cast irons, copper-manganese cast irons, and copper-molybdenum cast irons are tabulated.

Copper as an Alloying Agent in Steel and Cast Iron. C. E. Williams. (Mining and Metallurgical Society of America, Nov. 24, 1936 : Blast Furnace and Steel Plant, 1937, vol. 25, Apr., pp. 391–394,429). The author describes the characteristics of copper-bearing steels and cast irons and indicates some typical applications.

Titanium Improves Pearlitic Manganese Steel. G. F. Comstock. (Metals and Alloys, 1937, vol. 8, May, p. 148). The author shows the improvement in properties effected in pearlitic-manganese steel by deoxidation with titanium.

Investigation of Detachable Rock-Drill Bits. M. Mosier. (United States Bureau of Mines, 1937, Information Circular No. 6936). The third progress report on a national survey of the use of detachable bits in metal mines. It presents comparative costs of drilling with

conventional and detachable bits and describes the operating practice in rock drilling and the reconditioning of drill steel and bits at ten mines.

Cast Camshafts and Crankshafts Possess Many Advantages. F. J. Walls. (Society of Automotive Engineers: Foundry, 1937, vol. 65, Mar., pp. 28–30, 83–84; Apr., pp. 60–61, 163). The author describes the properties of cast camshafts and crankshafts used in automobile construction.

Heat-Resisting Steels for Boilers and High-Pressure Steam Pipes. D. J. Vishnjakov. (Metal Industry Herald, 1936, No. 15, pp. 48–57). The author has investigated the composition of spare parts for boilers and steam pipes imported from England, and finds that besides the usual carbon steels and low-alloy steels, some of them consist of highly alloyed steels with 12–15% of chromium and 22–36% of nickel. He suggests that chromium steel and chromium-nickel steel are to be preferred to nickel steel from the point of view of corrosion resistance, as well as from that of cost. (In Russian).

Hot-Working and Properties of Heat-Resisting High-Silicon Chromium-Molybdenum Steel. P. Michailov-Micheev and A. Chishik. (Metallurgist, Russia, 1936, No. 2, pp. 35–34). The authors found that the heat-resisting properties of a steel containing 0·5–0·75% of carbon, 16–17% of chromium and 1·6–1·9% of molybdenum were superior to those of a stainless steel containing a higher chromium content, and those of a steel containing 0·6% of carbon, 14% of chromium and 1·5% of molybdenum. The addition of silicon was found to increase the heat resistance, but rendered the hot-working of the steel difficult. (In Russian).

Chromium-Molybdenum Steels as Structural Materials of High Mechanical Strength. S. G. Bogdanov. (Katshestvennaia Stal, 1936, No. 8–9, pp. 31–35). The author investigated the mechanical properties of two chromium-molybdenum steels (2·3% chromium, 0·36% and 0·15% molybdenum). The critical points of the steels are 775° to 800° C. (Ac_1) and 825° to 850° C. (Ac_3). The best hardening temperature is 900° C. They acquire no impact brittleness on slow cooling after tempering. Their mechanical properties are equal to those of the best chromium-nickel steels. The impact toughness decreases considerably at low temperatures; the decrease is relatively slighter in the steel with the higher molybdenum content. Cooling in steps can be applied to these steels for obtaining material sufficiently soft for machining. (In Russian).

The Great Iron Chain. C. B. F. Young. (Iron Age, 1937, vol. 139, June 3, pp. 44–49). During the American War of Independence, iron chains were stretched across the Hudson River to prevent the passage of hostile ships. The author has examined specimens from these early iron chains and presents micrographs showing the structure.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 93 A–99 A)

How are Metallographic Sections for Microscopic Examination Prepared? F. Thiele and A. Kufferath. (Internationale Röhrenindustrie, 1937, vol. 2, June, pp. 10–14). The authors discuss the grinding and polishing of microsections and apparatus for use for this purpose, and then deal with the etching of the sections; they give a lengthy list of reagents for use with various metals and alloys and for revealing different structural characteristics.

Radiographic Examination of Welds. V. E. Pullin. (Institute of Welding Engineers, Mar. 22, 1937: Welding Industry, 1937, vol. 5, Apr., pp. 104–114). The author discusses the use of radiography for the detection of defects in welds, such as porosity, cracks, and non-penetration or lack of fusion, and shows how valuable information may be deduced from correctly taken radiographs.

Cold Drawn Steel is Inspected by Non-Destructive Method. R. K. Schrecongost. (Steel, 1937, vol. 100, May 17, pp. 56–57, 80). The author describes equipment and procedure for the magnetic testing of cold-drawn steels.

Micrographic Appearance of, and Hardness Tests on a Plain 1·70% Carbon Steel in Various Conditions. J. Seigle. (Revue de l'Industrie Minérale, Mémoires, 1937, No. 395, June 1, pp. 281–292; No. 396, June 15, pp. 327–339). The investigation described here forms a sequel to that of which an account was given earlier (*see* Journ. I. and S.I., 1936, No. II., p. 235 A). The plain carbon steel bars examined, containing 1·70% of carbon, were prepared by cementing 1% carbon steel rods, 5 mm. in dia., in wood charcoal for 10 hr. at 1100°. After discussing the position of a 1·7% carbon steel in the iron-cementite diagram, the author describes the microscopic features of specimens which had been (*a*) cooled slowly in various ways, (*b*) heated to 1150° and water-quenched at 20–25°, (*c*) heated to 1150°, furnace-cooled to some extent and quenched, (*d*) heated to 1150° and quenched in boiling water, (*e*) heated to 1150° and quenched in an air blast, and (*f*) heated to 1150° and only partially plunged into water. He next deals with the effects produced by heating to temperatures below 1000° and water-quenching; the appearance of a 1·7% carbon steel bar, heavily decarburised at the margin, quenched after heating to 1150°; the effect of cooling below zero after quenching; the effect of tempering after water-quenching; and of quenching in molten tin at 300°. The author then discusses the lamellar form of martensite in austenite, and records some magnetic tests made in the cold. Diamond-cone hardness tests are also reported.

A Proposed Standard Classification of Graphite in Gray Cast Iron. W. E. Mahin and J. W. Hamilton. (American Society for Testing Materials, 1937, Preprint No. 29). The need has been pointed out for a metallographic system of classification of the graphite phase in grey cast iron. Two proposed standard charts have been set out. One of these, serving to identify graphite flake size, is similar to the A.S.T.M. grain-size chart for steel. The other represents four types of association of graphite flakes differing from each other in their distribution or orientation. A technique for the application of these two charts has been proposed, with emphasis laid on the use of suitable magnifications in order to produce a record representative of the entire area of the microsection.

Differences in the Valuation of Grain-Size Testing in America and in Germany. H. W. McQuaid. (Stahl und Eisen, 1937, vol. 57, June 30, pp. 729–732). The author discusses the following topics: Grain-size testing as a means of supervising the uniformity of steel. Reasons for the choice of 927° C. as the case-hardening temperature in the McQuaid-Ehn test. Consideration of the grain size and hardenability in the choice of steel for particular applications. Reliability of the McQuaid-Ehn test; other methods for determining grain size. Importance of the abnormal behaviour of steel. Relationships between grain size abnormality and quench-hardenability.

Accelerated Method for the Determination of the Grain Size of Austenite. (Katshestvennaia Stal, 1936, No. 8–9, p. 56). The new method developed by the Ural Institute of Metals consists in placing the polished section, protected by iron turnings, cryptol powder or charcoal, in an iron tube at 930° for 1 hr., quickly placing it in a bath of fused $BaCl_2$, $CaCl_2$ and NaCl (equal parts) also at 930° for 1 to 2 min. cooling in paraffin oil, washing and drying. This method has so far been successfully applied to carbon steel (0·2 to 1·3% carbon) and will be tested for special steels too. (In Russian).

The Grain Growth of Electrolytic Iron and Some of Its Alloys Vacuum Melted. M. Hamasumi, T. Takano and K. Otomo. (Kinzoku no Kenkyu, 1937, vol. 14, Mar., pp. 107–112). The authors have studied the grain growth of cold-worked electrolytic iron, 3·45% nickel iron, and two types of transformer sheets, one containing 3·80% of silicon and the other 0·30% of phosphorus. (In Japanese).

Isothermal Transformation of Austenite in Special Steels and the Resulting Mechanical Properties. J. E. Kontorovitch. (Katshestvennaia Stal, 1936, No. 8–9, pp. 13–18). The author has investigated the kinetics of the decomposition of austenite in steels containing chromium, chromium plus molybdenum, chromium plus nickel, chromium plus molybdenum plus aluminium, and chromium plus nickel plus tungsten. (*a*) Magnetometric measurements.—Measured by the change in permeability, the decomposition of austenite takes place in chromium steels in the course of a few minutes

even at 100° C. Maximum velocity of decomposition is attained at 400° C.; it becomes slower at 700°. Steels with low carbon contents (0·2%) undergo the quickest decomposition. Chromium-nickel steels, as well as chromium-molybdenum steels with a high manganese content, have a much more stable austenite, decomposition requiring several hours at all temperatures. In chromium-nickel-tungsten steel, no decomposition of austenite takes place above 400° C. (*b*) Mechanical measurements.—Steels with unstable austenite become softer on isothermal annealing or on isothermal hardening, especially in thick pieces. Isothermal annealing, on the other hand, improves the mechanical properties of special steels with stable austenite. The effects of different methods of isothermal hardening and of hardening in steps are discussed. (In Russian).

Researches in the Field of the Ternary Iron Alloys. R. Vogel. (Metallwirtschaft, 1937, vol. 16, June 25, pp. 630–632). The author presents an enumeration, with brief comments, of the researches on various aspects of a number of ternary iron systems of alloys which have been carried out in the Metallographic Laboratory of Göttingen University.

The Iron-Manganese-Silicon System. R. Vogel and H. Bedarff. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, June, pp. 581–586). The authors have worked out the equilibrium conditions in the Fe–Mn–Si ternary system for the iron/manganese-silicide/iron-silicide field. It was found that a clearly distinguishable homogeneous solid solution of the composition $Fe_{12}Si_{11}Mn_5$ existed in this field, which must be regarded as a ternary compound. Further, three pseudo-binary sections were found: (1) FeSi–MnSi, (2) Mn_5Si_3–$Fe_{12}Si_{11}Mn_5$, and (3) FeSi–$Fe_{12}Si_{11}Mn_5$. Seven primary saturation surfaces were determined at which the following crystal types precipitated on cooling: (1) Ternary γ-manganese solid solution, (2) ternary β-manganese solid solution, (3) ternary γ-iron solid solution, (4) ternary α-iron solid solution, (5) crystals of the compound FeSi, (6) solid solutions of the FeSi–MnSi series, and (7) solid solutions of the Mn_5Si_3–$Fe_{12}Si_{11}Mn_5$ series. The conditions during solidification were determined by four transition planes (1160°, 1120°, 1020° and 1010°), and the transformations in the solid state indicated two four-phase equilibria (1000° and 720°).

The Alloys of Iron, Vanadium and Carbon. (Metallurgist, 1937, vol. 11, Apr., 30, pp. 23–25). A review of the work of various investigators on the iron-vanadium-carbon system.

Timken Research and Testing Facilities. (Blast Furnace and Steel Plant, 1937, vol. 25, Apr., pp. 388–390). Particulars are given of the equipment of the new laboratories of the Timken Roller Bearing Co. for the testing of roller bearings.

CORROSION OF IRON AND STEEL

(Continued from pp. 100 A–105 A)

New Photomicrographic Apparatus for Corrosion Tests. A. Kufferath. (Korrosion und Metallschutz, 1937, vol. 13, June, pp. 189–191). Apparatus for taking photomicrographs of the surface of corrosion test-pieces are illustrated and briefly described.

The Present Position of the Corrosion Problem in Steel Construction. K. Daeves and E. H. Schulz. (Stahlbau, 1937, No. 1). The rate of atmospheric corrosion of unalloyed unprotected steel amounts to about 0·02 mm. per year in clean country air and about 0·08 mm. per year in an industrial atmosphere; these values are averages from tests lasting for 8 years. In country air the rate diminishes progressively, so that at the end of 80 months it amounts to no more than 0·01 mm. per year. By adding 0·2–0·3% of copper and choosing suitable proportions of the other accompanying elements, particularly a high phosphorous content, the rate of corrosion can be reduced to about one-half of the above values (country air : 8-year average, 0·01 mm.; after 80 months, 0·006 mm. per year. Industrial atmosphere : 0·045 mm. per year). In atmospheric corrosion the effect of copper is developed only when the steel can dry off again completely and hence a dense protective film can form; under such conditions the effect is produced always and with certainty. Regarding the adherence of paint, both the surface condition and the composition of the steel have a great influence. Paint adheres best on sand-blasted or pickled parts made of copper-bearing steel. For the obtainment of long life for steel structures, therefore, attention must be directed to the choice of the steel, the cleaning process and the paint.

The Acid Resistance of Iron-Nickel-Base Alloys. M. Schmidt and L. Wetternik. (Korrosion und Metallschutz, 1937, vol. 13, June, pp. 184–189). The authors present the results of corrosion tests made on (*a*) iron-nickel alloys, (*b*) iron-nickel-molybdenum alloys containing nickel contents of 60, 35 and 28% with molybdenum up to 20%, (*c*) iron-nickel-copper alloys with similar nickel contents and up to 5% of copper, and (*d*) iron-nickel-molybdenum-copper alloys with the above-mentioned nickel contents, a constant copper content of about 2·5% and molybdenum up to about 20%. The specimens, in the form of cylinders 15 mm. in dia. and 10 mm. high, were polished to 000 emery finish; they were tested, in the as-forged and also the heat-treated condition (water-quenched from 1030–1050° C.), by immersion in 1 : 9 and 1 : 4 hydrochloric acid and in 1 : 4 sulphuric acid for 24 hr., after which the loss of weight of the cleaned specimens was determined. The alloys were also tested for " acid-fissuration." Sheets, 1 mm. thick, water-quenched

as above or water-quenched and heated to 700° C. for 5 min. and then polished, were placed in 1 : 99 hydrochloric acid or 1 : 9 sulphuric acid for 2 months at room temperature. They were then bent, if possible, through 180°, and note was taken whether the bend was undamaged, whether small or large fissures appeared at the bend or whether the material broke without any bending at all being possible. The results of all these tests are recorded in tabular and graphic form.

A New Method for Studying Cavitation Erosion of Metals. W. C. Schumb, H. Peters and L. H. Milligan. (Metals and Alloys, 1937, vol. 8, May, pp. 126–132). Illustrated particulars are given of the apparatus employed at the Massachusetts Institute of Technology for studying the cavitation of metals. By means of the apparatus it is possible to vibrate a solid in contact with a stationary liquid with sufficient intensity to result in cavitation. Intense vibrations of a frequency of approximately 9000 cycles per sec. are generated by the longitudinal vibration of a vertical nickel tube, the lower end of which is closed with a cap that is immersed in the liquid. Cavitation occurs in the liquid directly beneath the cap. The results of tests on caps of different metals are given, and the effect of the fluid properties on cavitation is discussed.

MINERAL RESOURCES

(Continued from p. 54 A)

The Mineral Wealth of Bulgaria. K. Konstantinoff. (Zeitschrift für praktische Geologie, 1937, vol. 45, June, pp. 87–94). The author presents a summary of the coal, ore and salt deposits of Bulgaria.

Geology of the Anthracite Ridge Coal District, Alaska. G. A. Waring. (United States Geological Survey, 1936, Bulletin No. 861). The Anthracite Ridge coal district is in south-central Alaska, about 200 miles from the coast at Seward. Coal-beds are exposed in three main areas within the district; at the north, on the central part of the ridge; at the east, in the basin of Muddy Creek; and at the south-west, along lower Purinton Creek. The district contains bituminous coal in addition to anthracite and semi-anthracite.

The Mineral Resources of China and the Importance of their Development. W. Wen-ho. (Metallwirtschaft, 1937, vol. 16, July 9, pp. 683–686). Among the minerals dealt with are coal, iron ore, tungsten and petroleum. The author indicates that the mineral wealth of China has been exaggerated, and considers various systems of development. The desirability or otherwise of foreign co-operation in developmental work is discussed, and the best means of effecting such co-operation are considered.

Mining in Indo-China. Reichelt. (Glückauf, 1937, vol. 73, July 10, p. 658). A review of the coal and ore production and exports from 1933 to the first half of 1935 and 1936. Figures are given for the output of tungsten, iron and manganese ores, together with output and export figures for anthracite and other coals.

Coal Formation in Space and Time. S. V. Bubnoff. (Glückauf, 1937, vol. 73, July 10, pp. 641–652). An historical and geological survey of the coal resources of the world.

World Energy-Resources. K. Rummel. (Stahl und Eisen, 1937, vol. 57, July 8, pp. 768–769). An account is given of the available coal and oil resources with brief indications as to their probable life, to the development of hitherto untapped supplies, and to methods of economical utilisation.

REFRACTORY MATERIALS

(Continued from p. 123 A)

Refractories. R. S. Hutton. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 817; Metals Technology, 1937, vol. 4, June, No. 4). A review of the advances made in refractories and a survey of the requirements expected of them, and of future developments.

20th Open-Hearth Proceedings. (American Institute of Mining and Metallurgical Engineers, 1937). This Report presents an account of the Proceedings of the Twentieth Open-Hearth Steel Conference of the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers, held in Apr. 1937. The following papers were presented under the general title of Refractories and Furnace Construction: W. J. McCaughey: Hearth Refractories for Steelmaking; B. C. Hutchinson: Description of New Furnaces at Inland Steel Company. Included under the same general title are discussions on these papers, and on other aspects such as the use of natural gas as fuel; and ladle linings.

The Selection of Chrome Ores for Use in Steel Furnaces. A. E. Dodd. (Iron and Steel Industry, 1937, vol. 10, June, pp. 497–498). The analyses of typical chrome ores used for refractory purposes are noted and the softening points compared. Their relative values as refractories are discussed.

A Note on the Refractoriness Under-Load Test. H. C. Briggs. (Journal of the Society of Glass Technology, 1937, vol. 21, June, pp. 264–269). The need for reliable data on the under-load characteristics of refractory materials is stressed, and the information yielded by various test methods is reviewed. Essential requirements of methods are indicated and new apparatus described which meets them. The means of eliminating the effects of expansion other than in the test piece are detailed.

Insulating Firebrick as a Furnace Lining. R. S. Bradley. (American Institute of Mining and Metallurgical Engineers, Feb. 3, 1937: Mining and Metallurgy, 1937, vol. 18, July, pp. 331–334). The author discusses the structure and physical properties of porous firebrick used for insulating purposes and compares these properties and the uses of the material with those of diatomaceous earth brick; tabula data and curves are given to illustrate the thermal properties of the brick as used for lining a car-type annealing furnace, and its service is compared with that of block-insulated firebrick employed on a similar furnace.

FUEL

(Continued from p. 124 A–128 A)

The Influence of the Process of Mixing on the Combustion of Gas and Air in Furnaces. II. K. Rummel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, July, pp. 19–30). A continuation of a previous article (*see* p. 124 A). The author describes further investigations of the influence of the mixing-process on the combustion of gas and air in furnaces by means of specially designed burners. The following conclusions were arrived at: (1) In most industrial furnaces with the usual type of burner, the velocity of mechanical mixing determines the time and space necessary for combustion. Where gas and air are mixed, combustion occurs at a velocity which for practical purposes may be taken as infinite. (2) This results in the fact that the temperature in the combustion zone has no appreciable effect on combustion-velocity between 900° and 1300° C. Apparently the temperature has no influence, even over wider limits, between the ignition temperature which approximates to 600° C. and the dissociation temperature of the gas. At higher temperatures greater expansion of the burning gases occurs and a correspondingly greater space is required for mixing. (3) The form of the combustion space influences the form of the space in which the mixing processes occur. (4) The greater the difference in the velocity of adjacent streams of air and gas emerging from one burner, the less is the space required for combustion, since turbulence at the interface increases. (5) The lower the velocity of air and gas from the burner, the greater is the space and time required for combustion, since less energy is available for turbulence. (6) Excess air decreases the space and time necessary for combustion throughout the entire process, and not merely towards its completion. (7) The space in which the combustion of gas and air is taking place forms a cone at the mouth of the burner when conditions are such that air, gas and products of combustion are present simultaneously; excess air or gas causes deflection of the cone. (8) The tendency of a high-velocity stream of a given specific gravity to rise in the furnace is slight with temperature differences below 100° C. (9) If an air stream lies over a stream of gas of a lower specific gravity, the tendency of the gas to rise is opposed. The mixing-action is intensified, and combustion occurs in less time and in a smaller space. (10) The composition of the " atmosphere " is strongly non-uniform until perfect mixing of gas and air has taken place, and where no value attaches to the occurrence of oxidising or reducing conditions in any given parts of the furnace, the replacement of round by flat burners is to be considered.

Clinkers in Furnaces, the Causes, the Remedies. L. Bro. (Chaleur et Industrie, 1937, vol. 18, Mar., pp. 105–114; Apr., pp. 175–182; May, pp. 215–224). The author presents a study of the causes of the formation of clinkers in furnaces and means for its prevention. In the first part he discusses the constituents of coal, the vegetable and mineral origins of the ash, the nature of ashes and the variation of their fusibility according to the preparation of the coal at the mine. In the second part the author deals with the formation of clinker during combustion and its removal in the various types of furnace. In the last part he discusses the choice of fuels, and the study of the fusibility of ashes in the laboratory.

A Review of Developments in Combustion Control Equipment. M. H. Mawhinney. (Industrial Heating, 1937, vol. 4, Jan., pp. 35–36; Feb., pp. 93–98; Mar., pp. 199–204, 208; Apr., pp. 273–276, 282; May, pp. 370–374, 384; June, pp. 443–446). The author discusses the importance of atmosphere control and tabulates the various types of burners. He also discusses furnace pressure controllers, flow meters, and furnace atmosphere analysers, also bright annealing.

Recent Developments in the Preparation of Coal. R. A. Mott. (Gas World, 1937, vol. 107, July 3, Coking Section, pp. 8–12). The author describes the advances made in mechanical methods of coal-cleaning, and modern processes for dedusting, water-clarifying and slurry-washing.

New By-Product Coking Installation at Cleveland. (Engineer, 1937, vol. 164, July 9, pp. 33–36; July 16, pp. 63–65; July 23, pp. 91–93). **Coke-Oven and By-Product Plant at Cleveland Iron Works.** (Engineering, 1937, vol. 144, July 9, pp. 36–38; July 30, pp. 118–120). **By-Product Coking Installation at Cleveland Works of Dorman, Long and Company, Limited.** (Iron and Coal Trades Review, 1937, vol. 135, July 9, pp. 41–52). **New Coking Installation of Dorman, Long and Co., Ltd.** (Colliery Guardian, 1937, vol. 155, July 9, pp. 49–54; July 16, pp. 95–99). A detailed account is given of the new coking installation at the Cleveland Iron Works, Middlesbrough. The description includes structural and operating data.

The Influence of Carbonising Conditions on Coke Properties. Part I. Mechanical Pressure. H. E. Blayden, W. Noble and H. L. Riley. (Iron and Steel Institute, Sept., 1937: this Journ. p. 47 P). Two Northumberland "non-coking" coals were carbonised under mechanical pressures ranging from 0·2 to 20 lb. per sq. in., and the effect of coal size was studied with one of these coals. The relative strengths of the cokes prepared were measured by a new apparatus which was devised for this purpose. The indices obtained show remarkably close correlation with other physical and chemical properties. Increase in carbonisation pressure produced a pronounced increase in the strength of the resultant coke. In certain cases the strength

index of the coke was raised from zero to that given by metallurgical cokes. The effect of pressure on coke strength is shown to depend on the coal size and grading. The coke strength decreased with decrease in size at low pressures and increased with decrease in size at higher pressures, with the coal examined. The cause of the observed influence of pressure is discussed.

Some Experiments in a Small-Scale Cupola. H. E. Blayden, W. Noble and H. L. Riley. (Iron and Steel Institute, Sept., 1937: this Journ. p. 25 P). The performances of some commercial and experimental-oven cokes and several carbons (electrode and retort carbon, petroleum coke, carbonised anthracite) were compared under similar operating conditions in a small-scale experimental cupola with a shaft 9 in. in internal dia. and giving a melting rate of 220–250 lb. per hr. of iron at about 1330° C. The rate of combustion and of melting were markedly affected by the coke size and rate of air supply. Metal temperatures appeared to be more sensitive to variation in the coke size than to variation in the air blast above certain limits, which were probably fixed by the cupola dimensions and design. The use of highly graphitised carbons in the cupola tended to the production of increased metal temperatures. The cupola performances of cokes made in an experimental oven from two normal Durham coking slacks and the same slacks blended with up to 30% of coke fines were similar under similar operating conditions. Blending a normal Durham coking slack with 5 and 10% of crushed dry peat also had little effect on the cupola performances of the resultant experimental-oven cokes. The experiments suggest that differences in the performances of cokes under practical conditions are largely attributable to differences in the mechanical strength of the cokes.

PRODUCTION OF IRON

(Continued from p. 129 A)

Sequence of Blast-Furnace Charging is Controlled Automatically. (Steel, 1937, vol. 101, July 5, pp. 77–78). A description is given of a new automatic blast-furnace charging control system, designed to control the movement of stock from scale car to the moment of charging into the furnace. It consists of motor-driven cam devices for actuating valves, a control panel, push-button control of bells, and limiting switches for hatchways.

The Use of Pig-Casting Machines. A. Vogelsang. (Stahl und Eisen, 1937, vol. 57, July 15, pp. 795–796). A brief description is given of the application of pig-casting machines at the Dagenham works of the Ford Motor Co.

Reports Upon Blast-Furnace Field Tests. I.—An Investigation of a Blast-Furnace Smelting Principally Lincolnshire Ores at the Frodingham Works of the Appleby-Frodingham Steel Co., Ltd. (Iron and Steel Institute, 1937, Special Report No. 18). This report, by the Blast-Furnace Reactions Research Sub-Committee of the British Iron and Steel Federation presents a short historical summary of previous investigations of the reactions occurring within the blast-furnace, and describes an investigation during which improved methods were devised and successfully established for the determination of temperatures at short intervals across selected horizontal planes in a blast-furnace, as well as for the taking of "gas" and "solid" samples almost simultaneously with each temperature measurement. In order to arrive at a true general perception of the conditions prevailing throughout the stack as a whole, it was necessary to deduce proper statistical averages for the numerous temperature measurements and gas compositions at each sampling point. In view, however, of the considerable variations in such measurements found at each sampling point, and of the importance of eliminating possible errors in the statistical methods employed for determining such averages, the whole of the data were submitted for independent examination to a statistical expert, who reported that, although an enormous number of measurements would have had to be made at each sampling point in order to arrive at an accurate "average" in each case, yet an adequate number had been made for arriving at a valid general view of the actual furnace conditions.

Such "average" results, while generally valid for the particular furnace and smelting conditions concerned, cannot be claimed to be necessarily applicable to other furnaces operating upon other ores and fuel, under widely different conditions as to rates of driving and distribution of the burden within the stack.

Perhaps the most striking and revealing feature of the results is the fact that the temperature and physico-chemical conditions were found to be far from uniform across any one of the selected horizontal planes in the furnace, thus proving that, in this particular case at all events, any conception of "uniformity" in the conditions across a given horizontal plane must be ruled out as fallacious. In fact, apart from a slight fall in temperature just at the inwall, doubtless due to the cooling effect of the stack-wall and its coolers, the temperatures observed across any given plane were usually higher at the centre and near the inwall than at intermediate points, and reached a minimum at points usually nearer to the inwall than to the centre. Moreover, in descending the furnace such minimum temperature points appeared to move away from the centre, although never approaching less than about 4 ft. from the inwall at any given plane.

Usually at any given point in any one plane in the upper part of the furnace, *e.g.*, 35 ft. below the stock-line, the instantaneous values of the CO_2 and CO contents in the gas followed the temperature in accordance with what would be predicted from the thermodynamical aspect of equilibrium in the principal reversible chemical reactions within the furnace. Moreover, the sum of the CO_2 and CO contents of the gas above this position was nearly a constant.

The expression log CO/CO_2 followed the temperature fairly closely at planes 26 ft. and 17 ft. below the stock line, but not so closely at the 35 ft. plane. The relationship existing for all the observations made during the investigation is shown.

Two diagrams show the lines of equal temperature and CO_2 content of the gases, respectively, throughout the furnace; they exhibit similar contours for such iso-lines, and particularly for those below 800° C., which may be regarded as characteristic of the working conditions of the furnace. These diagrams show that the furnace was working in what may be termed a centro-annular fashion, with a hot central core, a hot zone near the inwall, and cooler intermediate annuli—a circumstance doubtless connected with the size-distribution of the burden within the furnace. The position of the coldest region, corresponding with that of the highest CO_2 content in the gases, which was almost vertically beneath the periphery of the bell in the uppermost region of the furnace, tended on the whole to move outwards as the furnace was descended. Such conditions were reflected in the further fact that usually along any horizontal plane the degree of ore reduction was greater near the centre or the inwall than at intermediate points between them.

The first diagram also shows that while a definable temperature zone round about 750° C. undoubtedly existed in the upper regions of the furnace, it was so far from being horizontal that the investigation of the relative rate of ore reduction within it was found to be impracticable.

Since most of the stock samples contained iron as well as FeO, Fe_3O_4 and Fe_2O_3, it would seem as though some condition not usually present in laboratory experiments—when each successive stage in the ore reduction, $Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow FeO \longrightarrow Fe$, is substantially completed before the next begins, there being only slight overlaps at the transition points—existed in the blast-furnace. Indeed, it would appear that in the furnace, as opposed to laboratory experiments, the ore may be as much as 70% reduced and yet retain nearly 30% of its iron as Fe_2O_3, instead of the oxide then being wholly FeO. This circumstance may be due to the larger size of the ore relative to the gas velocity at its surface, and its slower penetration by the gases in the blast-furnace than in most laboratory experiments.

The results of the investigation as a whole may be said to have stressed the importance of the proper sizing and distribution of the solid burden within the furnace. The material comprising the burden of this particular furnace varied in size from lumps of ore weighing 60 lb. (and sometimes more) down to dust, and were charged into the furnace from a bell 13 ft. in dia. with an angle of 45°. The fines and smaller pieces fell from it almost vertically, while the large pieces rolled down towards the centre and the wall, so that the stock-line assumed a wavy contour. And it is principally to such size-distribution of the burden within the stack that the characteristic graphs for equal temperatures and equal CO_2 contents, respectively, may be ascribed.

A further cause of irregularity in the working of this furnace may perhaps be variations in the compositions of the ores used (apart from a small amount of foreign ore), not only from stratum to stratum in the beds, but also along (and away from) the working faces in the mines. The heterogeneity comprised not only the chemical composition, but also the size and hardness of the component strata; consequently a change in the chemical composition of the rocks composing the ores would most likely be accompanied by an alteration in the proportions of the various sizes present. Thus, although a chemical analysis used in burdening the furnace may be used also to determine fairly accurately the ultimate slag composition, it gives no information concerning the changes which will occur in the conditions within the stack when a changeover or alteration is made, because it does not take into account the effect of the physical properties, size and distribution of the component elements throughout the different sizes.

Another factor connected with size-distribution is the influence which it might be expected to exert upon carbon deposition in the upper region of the furnace. In the case of the particular furnace under investigation, it is clear that the most favourable region for carbon deposition would be directly beneath the rim of the bell where the temperature was lowest, the gas velocity slowest, and the ore size smallest. As carbon impregnation and deposition

proceeded "voids" would close up, with a further slowing of the gas stream and increase in the time of contact between the gas and ore in the region concerned, the initial irregularity becoming accentuated thereby.

A New Method for Judging the Behaviour of Iron Ores during Reduction. N. J. Klärding. (Iron and Steel Institute, Sept. 1937: this Journ. p. 223 P). After a brief reference to the reactions occurring during the reduction of iron oxide by carbon monoxide and a method and apparatus for investigating them, reduction curves for pure Fe_2O_3 obtained by Schenck and Dingmann are presented, and the influence of the temperature on the conversion of carbon monoxide into carbon dioxide is indicated. The phases formed in the iron-oxygen system as a result of these reactions are then enumerated. Finally, isothermal reduction curves for ores from Rio Tinto, Newfoundland and Lucainena (Spain) are presented and discussed.

A Statistical Method of Investigation of the Oxidation and Reduction Equilibria of Iron by Water Vapour. K. Iwasé and K. Sano. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 461–475). The following equilibria were investigated:

$$3Fe + 4H_2O \rightleftharpoons Fe_3O_4 + 4H_2$$
$$Fe + H_2O \rightleftharpoons FeO + H_2.$$

Special apparatus designed by the authors which eliminated the effects of thermal diffusion, was employed. The results obtained—

$$(430° \sim 552°) \log K_p = \frac{-1707{\cdot}5}{T} + 1{\cdot}590(\tfrac{1}{4}Fe_3O_4 + H_2 \rightleftharpoons \tfrac{3}{4}Fe + H_2O)$$

$$(574° \sim 692°) \log K_p = \frac{-654{\cdot}0}{T} + 0{\cdot}321(FeO + H_2 \rightleftharpoons Fe + H_2O)$$

are in fair agreement with those of Kapustinsky. Some thermodynamic values for magnetic and ferrous oxide are calculated.

Influence of the Intensity of Operation on the Gas Balance of Blast-Furnaces in a Siderurgical Works. M. Steffes and R. Welter. (Chaleur et Industrie, 1937, vol. 18, May, pp. 209–213). The gas balance of the blast-furnaces in a siderurgical works was studied as a function of the "rhythm" of operation. Starting out from statistical data, the authors established simple laws of variation, by which, in particular, the magnitude of the lack or excess of gas with a given furnace output can be calculated.

Foamed Blast-Furnace Slag. T. W. Parker. (Iron and Steel Institute, 1937, Special Report No. 19). An investigation was carried out on the suitability of foamed blast-furnace slag as a lightweight concrete aggregate.

Particular attention was paid to verifying that slags which normally "fall" on slow air-cooling are stabilised by foaming. A range of slag compositions was therefore used, of which the

majority of the individual samples had a high lime content, such as would cause falling if the slags were slowly cooled in the normal way. Experimental foaming tests were made on these, and observations were made on the foamed products under a variety of weathering and storage conditions. Attempts were also made to accelerate any disintegrating effects by annealing and by water and steam treatments. No evidence of falling in these foamed slags was observed, and it is concluded that foaming stabilises falling slags, at least in the range of compositions examined (*i.e.*, up to lime contents of 50%).

Attention was also paid to the question of whether the contents of sulphur compounds in the foamed slags are likely to be at all deleterious when the material is used in concrete. No free sulphur as such exists in blast-furnace slag, but a certain amount is always present chemically combined as sulphide or sulphate. The two objects of the tests were to determine whether steel reinforcement in concrete would be affected by the sulphide, and whether the cement would be attacked by the sulphate. In agreement with the results of other investigators, it is concluded that the foamed slag concrete is not intrinsically corrosive to the steel; on the other hand, the protection afforded to steel by lightweight concrete, whether made with foamed slag or other lightweight aggregate, is not so complete as that given by heavy aggregates. An examination was made to determine whether sufficient sulphate is present in foamed slags to produce an expansion by reaction with the cement in the presence of moisture. A test was devised to determine the "available sulphate," on the assumption that only the sulphate in the surface layers of the aggregate would be reactive to the cement. The permissible limit of available sulphate, by the suggested method, was assessed at 0·5%, this being based on the experience of the Building Research Station with other lightweight aggregates, and on long-period strength tests on foamed slag concrete. All but one of the samples had available sulphate contents below the permissible limit.

Tests were devised which are considered to be suitable for use in standard specifications for foamed slag.

A detailed account of the properties of foamed slag concrete, based on the results of tests at the Building Research Station, is in course of preparation and will be published elsewhere, but a summary of these results is included in the present publication. It is concluded that the strength of the concrete varies in a general way with the weight per cubic foot. On the whole, the materials examined gave concretes showing higher strengths than concretes made with other lightweight aggregates, although the weights per cubic foot were higher than those of the lighter types of lightweight aggregate. Such properties as thermal insulation, moisture movement, ease of plastering, &c., were comparable with those of the lighter types.

FOUNDRY PRACTICE

(Continued from pp. 130 A–131 A)

The Progress of Foundry Practice. J. E. Hurst. (Engineer, 1937, vol. 163, May 28, Supplement, pp. i–ii). An historical account is given of the evolution of the modern foundry, followed by a review of output figures, the development of production methods, an account of foundry metallurgy, and concluding with an outline of education and training facilities for the foundry industry.

Foundry Equipment. (Engineer, 1937, vol. 163, May 28, Supplement, pp. iii–xxxii). A detailed description is given of foundry equipment, including plant for transport, handling, preparation of sand, moulding and charging, as exemplified in British, American and Continental practice. The various tools and machines are classified under the names of the manufacturing firms.

Hydraulic Fettling. (Engineer, 1937, vol. 163, June 18, p. 706). A description is given of an hydraulic fettling plant for cleaning heavy castings. A pump delivers water at 550 lb. per sq. in. on to the casting mounted on a rotary table in an enclosed chamber. Considerable economy in time is claimed.

Wasters—Their Cause and Cure. (Iron and Steel Industry, 1937, vol. 10, June, pp. 479–482). A continuation of a series of articles reviewing the causes of wasters in foundry practice. Faulty moulding technique is dealt with in this section. (*See* p. 65 A).

A Balanced-Blast Cupola in Operation at the Batawerke, Zlin, Czechoslovakia. A. Hübner. (Strojnický Obzor, Feb. 20, 1937 : Bulletin of the British Cast Iron Research Association, 1937, vol. 5, July, pp. 10–11). A record is presented of experiences in the use of the B.C.I.R.A. balanced-blast cupola. The economies effected are shown in tabular form.

Determination of the Basin Capacity of a Cupola. J. A. Bowers. (American Foundrymen's Association, 1937, Preprint No. 37–6). To determine the space in a cupola basin available for molten iron, tests were carried out on a hand-charged cupola using foundry coke of 3 in. and over. The metal was made up into 3000 lb. charges, coke splits weighing 250 lb., and 80 lb. of dolomite being used to each charge of coke. The cupola basin was measured before each heat, and capacity determinations were made after the basin had assumed a reasonably average condition. The melting rate was checked by taking the time which elapsed between the appearance of slag at the tap hole and the appearance of iron at the slag notch, and the time for slag to again appear at the tap hole on draining; the iron collected was measured and divided by the time deduced as above, the melting rate being thus obtained. By taking the time

required to refill the basin and employing the pre-determined melting rate, the basin capacity was calculated.

Cupola High-Test Cast Iron. R. S. MacPherran. (American Foundrymen's Association, 1937, Preprint No. 37–19). Defining high-test cast iron as iron possessing a tensile strength of over 22 tons per sq. in., the author describes the production of such metal at the Allis–Chalmers Manufacturing Co. The effect of alloy additions is discussed, although it is possible to produce such irons without these additions. Cupola-melting procedure is described, particularly in relation to carbon control. The mechanical testing of the material is examined critically from various angles. The duplexing process and its uses are described in concluding the paper.

Some Heat Treatments of Whiteheart Malleable Cast Iron. J. V. Murray. (Metallurgia, 1937, vol. 16, June, pp. 47–50). Blackheart and whiteheart malleable cast irons are discussed, and reference is made to the difficulties surrounding the manufacture of the latter. The need for control is stressed, and the high-tensile strength of whiteheart malleable when correctly made is emphasised. The results of various experimental heat treatments on this iron are described, and its wide sphere of usefulness is indicated.

The Manufacture of Steel Castings. Dadswell. (Keighley Association of Engineers : Alloy Metals Review, 1937, vol. 1, June, pp. 37–39). The author deals with the practical essentials in the production of steel castings.

Sand Control in a Malleable Foundry. E. C. Zirzow. (American Foundrymen's Association, 1937, Preprint No. 37–2). The factors in moulding sand control are detailed, and an outline is given of the handling methods employed at the National Malleable and Steel Casting Co. Routine testing methods are discussed, and the successful use of fuel oil in the sand is noted. The control of core sands is discussed fully, and graphical data on variations in properties over fixed periods are presented.

A Correlation of the Physical and Chemical Properties of Clays with the Durability of Moulding Sands. C. E. Schubert. (American Foundrymen's Association, 1937, Preprint No. 37–3). The author compares the mould test, the oven test, and the hydration and re-hydration tests for determining the durability of moulding sands. The tests and the necessary equipment are described, and the results are given for green permeability and compression, dry permeability and compression, clay content and fineness tests. The constituents of the clays were determined petrographically, and their effects studied. Information is given on their properties and their base-exchange capacities. The author concludes that none of the proposed testing methods yields an indication of the life of the sand, and that the most satisfactory and economical method of treating the sand is to add a bond after the sand has been used for a number of heats rather than to maintain its quality by constant additions. Durability is concluded to depend *inter alia* on the

physical and chemical properties of the mineral or minerals in the bond.

Application of Compressed Air for the Conveying and Ramming of Foundry Sands. F. Rolff. (Giesserei, 1937, vol. 24, July 16, pp. 368–371). The development of processes employing the transport of sand by compressed air is traced from the sand-blast apparatus which is characterised by the use of dry sand, to the sand-slinger and mould- and core-blowing machines where the sand is in a plastic state.

A Study of Core Hardness. M. W. Dietert and E. Woodliff. (American Foundrymen's Association, 1937, Preprint No. 37–12). The author describes a scratch test devised as a means of determining the quality of a baked core. Defined as hardness, the property measured is examined in relation to the known factors affecting the quality of a core, and its usefulness is appraised. A standard procedure for testing is outlined.

Modern Vertical Core Ovens. C. A. Mauch. (Iron Age, 1937, vol. 140, July 1, pp. 26–28). Structural details and operating data are given for the vertical core oven installed by General Motors Corporation at Saginaw Malleable Iron Division. The oven is fired with natural gas of 1100 B.Th.U.

Production of Some Iron Castings for Steel Works. J. Roxburgh. (American Foundrymen's Association, 1937, Preprint, No. 37–10). Detailed explanations are presented of the problems encountered in the production of large castings for steelworks, particularly ingot moulds, anvil blocks and cylinders, the life of the first being measured by the number of ingots it will produce. Service conditions for the castings are detailed, and the type and composition of the iron required are described. The manufacture of a 40-ton ingot mould made by loam-moulding is described, together with the production and composition of anvil blocks, cylinders and liners.

Founding of Pressure Castings. M. H. Judson. (American Foundrymen's Association, 1937, Preprint No. 37–7). The author describes the practice at the plant of Goulds Pumps, Inc., for manufacturing pressure castings. Two types of iron are used, one for pressures above 500 lb. per sq. in. and one for pressures below 200 lb. per sq. in.; the iron for high-pressure work contains additions of steel, while for low pressures no such addition is made. A detailed account is given of the "two-cupola" method employed for the high-pressure iron, including cupola operating data and the analysis of the final product. Moulding and casting technique are treated in detail.

PRODUCTION OF STEEL

(Continued from pp. 132 A–134 A)

The Thomas-Gilchrist Basic Process, 1879–1937. F. W. Harbord. (Iron and Steel Institute, Sept. 1937 : this Journ. p. 77 P). The author gives a short account of the early life and training of Sidney Gilchrist Thomas and of the development of the Thomas-Gilchrist process from the early experiments carried out in the 6-lb. converter to the present-day production of 90,000,000 tons of basic steel per annum. After describing the experiments at Blaenavon, and the assistance given by the late E. P. Martin, he shows how, by the enterprise of Messrs. Bolckow, Vaughan and Co., Ltd., acting on the advice of the late E. Windsor Richards, the commercial and technical possibilities of the process were demonstrated to the world. He refers to some of the difficulties encountered and indicates how, by the courage and persistence of Windsor Richards, success was finally achieved. He then traces the development of the process on the Continent, in Great Britain and in America, and points out that the general tendency in recent years for the basic open-hearth process to supersede the basic Bessemer process is largely a matter of the wide distribution of suitable ores containing insufficient phosphorus for producing a pig iron suitable for basic Bessemer practice, and how this is especially noticeable in America, where 43,000,000 tons of steel were produced by the basic open-hearth process last year (1936). The conditions under which the basic Bessemer process had to operate in Britain with the ores available are sketched, and the re-introduction in this country of the basic Bessemer process by Messrs. Stewarts and Lloyds, Ltd., at Corby is referred to.

The author then deals with the influence which the basic process has had on the railway, shipbuilding and engineering industries, and on the world as a whole, and points out that the present world production of basic steel involves the mining of not less than 250,000,000 tons of phosphoric ore per annum, which otherwise could not have been used for steelmaking, and that since the introduction of the Thomas-Gilchrist basic process it is estimated that not less than 22,000,000 tons of phosphoric acid as basic slag have been returned to the land to enrich the soil. Finally, the author refers to Thomas as a man and the loss to the world by his early death.

Hot Metal Practice in Five Melting Shops on the North-East Coast. W. Geary. (Iron and Steel Institute, Sept. 1937 : this Journ. p. 229 P). Attention has recently been called to the hot metal practice of the North-East Coast of England, of which no recent account has been published. This paper describes the methods in present use by reference to the construction and operation of five plants. Each plant is

separately described and completely discussed. The history of each is briefly mentioned and its subsequent development sketched. The plant layouts are described and adequately illustrated. The constructional details of mixers and varying designs of steel furnaces are mentioned and illustrated. The furnaces described vary from 55 tons to 250 tons capacity. Steelmaking practice is described in detail for the various furnaces and plants, the layout of plant and design of furnaces necessitating certain modifications of practice. Data are supplied for complete charges, with accounts of analyses of materials and details of pressure measurements. Recent modifications in furnace construction are referred to; and a very fully detailed account is given of the author's experience when working the standard hot metal process in cold coke-oven-gas furnaces of modern design. The fuel consumption on these furnaces is given; for the more usual heating the gas supply and its utilisation are discussed, and results are given. Casting practice is described and the nature of the products indicated. Certain observations are made concerning points that experience indicates to be of prime importance or of special interest, including the supply of materials, the effect of furnace design or shop layout, and fuel.

20th Open-Hearth Proceedings. (American Institute of Mining and Metallurgical Engineers, 1937). This Report presents an account of the Proceedings of the Twentieth Open-Hearth Steel Conference of the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers held in Apr. 1937. Included among the papers presented are the following: T. L. Joseph: Pig-iron Quality; P. J. McKimm: Basic Open-Hearth Pig Iron; J. D. Sullivan: Residual Metals in Open-Hearth Steel; R. C. Good: Manufacture of Rimming Steel; P. J. McKimm: Manufacture of Low-carbon Steel by the Basic Open-Hearth Process; J. Chipman: Effect of Slag Composition upon Oxygen, Carbon and Sulphur in the Bath; G. D. Tranter: Safety and Training in the Open-Hearth. Discussions follow the papers, together with further discussions on cognate problems.

Oxides in Basic Pig Iron and in Basic Open-hearth Steel. T. L. Joseph. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 804; Metals Technology, 1937, vol. 4, June, No. 4). The temperatures of several hundred casts of basic iron produced in a 700-ton furnace operating on Lake ores were measured with precious-metal thermocouples to determine the effect of temperature upon the oxides in the iron. A definite relation between silicon and sulphur was established, but no relation was found between the oxides in the iron and the temperature of the iron. Close control of silicon and sulphur necessitates the holding of the temperature within very narrow limits. The total oxides in the iron ranged from 0·012 to 0·313%, and with increasing total oxides, the percentage of ferrous oxide in the residue increased. The oxide residues from 194 casts averaged 22% of silica, 14% of

manganese oxide and 64% of ferrous oxide; a small amount of alumina was found in certain casts. The oxide content of the iron had no apparent effect on the form of the graphite, and no consistent relationship was found between blast-furnace practice and the oxides present. A relation established between the carbon and total oxygen in 150 aluminium-killed samples shows that the ferrous oxide in the bath before deoxidation is primarily a function of the carbon content. In rimming steel, the ferrous oxide introduced into the bath to eliminate carbon is mainly eliminated by reaction with the carbon and by the rimming action in the ingot mould, while in killed or semi-killed steel it is reduced to metallic iron by deoxidisers. Procedure for the electrolytic extraction and analysis of oxides in iron and steel is reviewed.

Basic Open-Hearth Slags in the Scrap-Carburising Method. E. Widawski. (Stahl und Eisen, 1937, vol. 57, July 15, pp. 781–789). From numerous experimental melts produced by the scrap-carburising process it was determined that a basicity of about 66 in slags amounting to 60–90 kg. per ton of steel led to a high manganese consumption. Further additions of lime, and a corresponding increase in the quantity of slag produced and in its basicity, promote the loss of manganese by oxidation and lower the quality of the steel.

Important Factors to be Considered in Acid Open-Hearth Furnace Practice. T. Fujiwara. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 567–580). Records are given of experiments carried out in connection with actual melting practice on a 50-ton acid open-hearth furnace. The ferrous oxide content of the slag is indicated on a colour chart and shows the nature of the heat, while the colour of the slag and the fracture of the steel during the final stages of refining indicate the type of heat obtained. Both conditions may be estimated by the type of curve obtained on plotting the carbon content at each stage, particularly at the time of lime addition. Silicates should be removed primarily at the boiling stage, and finally during the working of the heat, by the use of limestone for example. Silicates formed at the final stage of melting may be removed according to the principle of Stokes.

Deoxidation of Molten Steel. C. Sharp. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1937, vol. 10, June, pp. 483–486). After a brief account of the purpose and mechanism of deoxidation, a description of modern deoxidants is given. Methods of primary and final deoxidation are discussed, and the uses of zirconium and calcium-silicon alloys are considered.

The Effect of the Formation of Silicides, Phosphides and Carbides on the Oxygen-Equilibrium of Molten Iron. F. Körber and W. Oelsen. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 558–566). The shifting of the equilibria in metal-slag reactions in steel-making

processes using acid slags with increasing silicon, carbon and phosphorus contents, is discussed. The heats of formation of iron-silicon alloys were determined in the solid and liquid states. The results indicate the effect of the formation of silicides, phosphides, and carbides upon the slag-metal equilibrium, and permit conclusions to be drawn as to the type and stability of these compounds in the melt.

The Equilibrium between Carbon and Oxygen in Molten Steel. S. Matoba. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 548–557). The equilibrium of the iron-carbon-oxygen system at the temperatures employed in steelmaking was studied by melting carbon- and oxygen-bearing iron in a stream of carbon monoxide and dioxide. The oxygen content of molten steel in equilibrium with the gas phase is shown to be proportional to the ratio $p\mathrm{CO}_2/p\mathrm{CO}$, and the carbon content to $p^2\mathrm{CO}/p\mathrm{CO}_2$. On this account the author considers that the equilibria $\mathrm{FeO}_{(\mathrm{Fe})} + \mathrm{CO} \rightleftharpoons \mathrm{Fe} + \mathrm{CO}_2$ and $\mathrm{C}_{(\mathrm{Fe})} + \mathrm{CO}_2 \rightleftharpoons 2\mathrm{CO}$, should be taken simultaneously as the carbon-oxygen equilibrium in steelmaking, in place of the hitherto accepted form $\mathrm{FeO}_{(\mathrm{Fe})} + \mathrm{C}_{(\mathrm{Fe})} \rightleftharpoons \mathrm{Fe} + \mathrm{CO}$.

On the Deoxidation Process in the Electric-Arc Furnace. T. Yajima. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 581–603). The author describes a method of determining the oxygen content of metals by an improved form of vacuum fusion apparatus. The deoxidation process in the arc furnace is then studied by means of oxygen analyses on three heats of low, medium and high carbon steel. The segregation of oxides in the ingot is also examined.

The Ternary System FeO–$\mathrm{Al_2O_3}$–$\mathrm{SiO_2}$. R. Hay, J. White and T. H. Caulfield. (Journal of the Society of Glass Technology, 1937, vol. 21, June, pp. 270–280). The diagram for the FeO–$\mathrm{Al_2O_3}$–$\mathrm{SiO_2}$ system has been constructed from thermal and microscopical data; the molybdenum wire wound furnace used and the technique employed for obtaining the curves are described. Four ternary combinations are shown to occur, together with three ternary eutectic points closely allied in composition to fayalite. The significance of the deep narrow trough running behind the silicon-rich region of the ferrous oxide–silica system is noted.

Developments in Steel Plant Distribution Systems. M. H. Hobbs. (Iron and Steel Engineer, 1937, vol. 14, June, pp. 22–30). An account is given of the factors which determine the design of a distributing system for electric current in steel plants, and methods of evaluating these factors. Some typical systems are described, and details are given of modern switchgear available for use on this equipment and actually being applied.

Internal Stress due to Cooling in Spherical Steel Ingots. T. Hirone. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1017–1030).

The formulæ for internal stress in a spherical steel ingot during cooling, and those at room temperature are derived on the assumption that steel is elastico-viscous above a certain temperature, and perfectly elastic below that temperature. By using these formulæ, the internal stress during cooling in a spherical ingot of nickel-chromium steel 80 cm. in dia. is calculated. The results of the calculation are summarised as follows: (1) When the steel is assumed to become elastic above the $Ar_{3\cdot1}$ points the middle of the ingot is stressed in tension which reaches a maximum just before the occurrence of transformation. The stress in the central portion of the ingot is greatly increased by the presence of the $Ar_{3\cdot1}$ transformations. (2) When the temperature at which the steel becomes elastic coincides with that of the transformation, internal stress is reduced, and compression stress occurs in the centre of the ingot. (3) In both cases this tangential component of stress is always compressive at the outer parts of the ingot.

FORGING, STAMPING AND DRAWING

(Continued from p. 136 A)

Drop Forging Association Adopts Standard Tolerances for Forgings. (Heat Treating and Forging, 1937, vol. 23, May, pp. 224–226). A specification for standard tolerances adopted by the Drop Forging Association, Cleveland, Ohio, is given.

Cold Heading Problems. C. L. Harvey. (Wire and Wire Products, 1937, vol. 12, July, pp. 359–361). The double extrusion process is described and the characteristics of the wire used in it are defined. The " scrapless nut " process is also dealt with. The nature of the special requirements as to surface finish, heat treatment and analysis are discussed in relation to cold heading generally.

Contribution to the Study of Methods of Drawing Sheet Metal. Mijon. (Arts et Métiers, 1937, vol. 91, Apr., pp. 86–93: Sheet Metal Industries, 1937, vol. 11, June, pp. 535–542, 561). The author describes the choice of tools employed, the limits of drawing-depth, factors governing these limits, and the strength of the metal drawn, in connection with the drawing of sheet metal. The peculiarities concerning stresses involved in the various operations are examined.

Effect of the Stress-Strain Curve on the Blanking Properties of Mild Steel. J. D. Jevons. (Sheet Metal Industries, 1937, vol. 11, June, pp. 547–548). The author records the results of an investigation to determine what differences in the properties of dead mild steel sheet cause a certain marked variation in behaviour during blanking. It is concluded that when sheet steel is in the most suitable condition for pressing or deep-drawing, it is in an unsuitable condition for blanking with cleanly cut edges.

A Milestone of Metallurgical Progress. (Wire and Wire Products, 1937, vol. 12, July, pp. 352–358). A description of the new Firthaloy sintered carbide plant, McKeesport, Pa. The production of sintered carbide dies, mandrels and tools is outlined.

New Type of Spring Coilers. (Wire and Wire Products, 1937, vol. 12, July, pp. 362–363). An outline is given of the main features of three recently developed machines for coiling and straightening wire, and for producing torsion springs.

Flash Baking of Wire and Rods. (Wire and Wire Products, 1937, vol. 12, July, pp. 350–351, 385). The evolution of the flash baker employing high velocity air at 750° F. is described, together with its operating features and special technical and economic advantages.

ROLLING-MILL PRACTICE

(Continued from pp. 137 A–139 A)

Concerning the Flow-Process during the Hot Rolling of Rods. H. Unckel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, July, pp. 11–17). Investigations were undertaken to extend the results obtained by earlier workers on the flow of material in grooved rolls. The deformation processes occurring in rolled specimens of different materials were examined during a series of reductions, with passes in various directions, and comparison was made between surface and core deformation by means of flow determinations on etched sections. Copper and aluminium rods were employed.

Four-Ball Top for Testing the Boundary Lubricating Properties of Oils under High Mean Pressures. G. D. Boerlage and H. Blok. (Engineering, 1937, vol. 144, July 2, pp. 1–2). By means of this machine which employs the four-ball principle utilised in apparatus for testing extreme-pressure lubricants, the influence of temperature on the friction coefficients for various oils were tested and plotted in temperature-friction coefficient curves. The influence of combinations of different metals on boundary lubricating were also studied.

Continuous Rod Mills are Set Parallel in New Plant. (Steel, 1937, vol. 100, June 28, pp. 41–43). A description is given of plant layout and operating conditions in the rod mill of the American Steel and Wire Co., where two new parallel continuous mills have recently gone into operation.

Morgan Supplants Garrett at Joliet. T. W. Lippert. (Iron Age, 1937, vol. 139, June 24, pp. 30–35). Describes a modern continuous rod rolling unit in operation at the Joliet plant of the American Steel and Wire Co.

Rolling Mill Developments in the U.S.S.R. Two-High Reversing Mill at the Dsershinski Steelworks. (Iron and Steel Industry, 1937, vol. 10, June, pp. 475–477). An account is given of the universal rolling-mill plant at the Dsershinski Steelworks in the U.S.S.R. The plant incorporates two continuous-type furnaces, one universal rolling mill with roller tables, and finishing equipment.

New 100″ Semi-Continuous Plate Mill; Carnegie-Illinois Steel Corporation. (Iron and Steel Engineer, 1937, vol. 14, June, Supplement, pp. 1H–11H). A detailed account is given of the construction and layout of the Homestead 100 in. semi-continuous plate mill.

New Method Imparts Stiffness to Cold-Rolled Tin Plate. (Steel, 1937, vol. 100, June 28, pp. 56–57). Difficulties experienced as a result of the high ductility of cold-rolled sheets were not successfully solved by the use of alloy sheet nor by the use of heavy skin passes. A new process is noted which produces from any desired type of

steel, by means of controlled heat treatment and distributed cold rolling, sheet with equal strength both with and across the grain. The process may be controlled to yield pre-determined properties with and across the grain.

The Determination of Working Time on a Steckel Mill. (Metallurgia, 1937, vol. 16, June, pp. 43–44). A practical method is developed for calculating the time involved in rolling strip on a Steckel mill; it may be applied to suit various given conditions obtaining in different works.

Runout Table Drives for Modern High-Speed Wide Hot Strip Mills. W. R. Hough. (Steel, 1937, vol. 100, June 21, pp. 57–58, 60, 62). A brief historical review of individual motor drives as applied to handling systems for continuous mills, is followed by a detailed account of studies and tests carried out to determine whether d.c. motors or squirrel-cage induction motors are most suitable for driving conveyor table rollers and coilers.

Mechanical Transmission. Choosing the Correct Method. W. Staniar. (Iron and Steel Engineer, 1937, vol. 14, June, pp. 31–38). After a preliminary discussion on the problems associated with the choice of transmission gear to suit given conditions, a description of various devices for obtaining rigid or flexible drive is given. Some discussion follows on the respective merits of group and individual drives, the methods for achieving either rigid or flexible transmission being then subjected to a more detailed examination.

Electricity in Steelworks. (Electrical Review, 1937, vol. 120, Apr. 16, pp. 567–580; Apr. 23, pp. 607–620). A series of articles is presented describing electrical equipment and its applications in iron and steel works, and comprising the following aspects :

Modern Steelworks Practice.
Steelworks Supply and Distribution, by P. F. Grove.
Public Supply for Steelworks.
Steelworks Private Generation Schemes.
Economical Operation, by H. G. Weaver.
Electric Furnace Development, by D. F. Campbell.
Steel Making.
Heavy Rolling Mill Work.
Manufacturing Sheet and Strip.
Reversing Rolling Mill Drives, by H. S. Carnegie.
Electrical Equipment in Wide-strip Mills, by W. E. Taylor.
Drives for Cold Strip Rolling Mills, by W. B. Green.
Steelworks Auxiliary Drives, by H. Nielsen.

HEAT TREATMENT

(Continued from p. 140 A–141 A)

Metallic Cementation (XII). Cementation of Vanadium on Some Metals. T. Kase. (Kinzoku no Kenkyu, 1937, vol. 14, Apr. 20, pp. 120–129). Iron and nickel were cemented for 1 to 5 hr. at 850° to 1300° C. in pulverised ferro-vanadium (80·97% of vanadium, 0·02% of carbon, balance iron). The cemented surfaces were tested for depth of penetration, and microscopic and chemical analyses and corrosion tests in some acids were carried out. Diffusion begins below 900° C. and hardening of the surface occurs. Resistance to the attack of iron by nitric acid is increased due to the surfaces becoming passive, but otherwise no advantages in this direction are noted. The relationship between the depth of penetration and the absolute temperature of cementation is formulated. (In Japanese).

Metallic Cementation (XIII). Cementation of Tantalum on Some Metals. T. Kase. (Kinzoku no Kenkyu, 1937, vol. 14, Apr. 20, pp. 130–140). Iron and nickel were cemented for 1 to 5 hr. at 800° to 1300° C. in pulverised ferro-tantalum (84·24% of tantalum, 0·11% of carbon, balance iron). The cemented surfaces were tested for depth of penetration, and microscopic and chemical analyses and corrosion tests in some acids were carried out. Diffusion begins below 800° C. The surface of the iron hardened rapidly, but that of the nickel only slightly. Increased resistance to corrosion by sulphuric and hydrochloric acid is shown. The relationship between depth of penetration and the absolute temperature of cementation is formulated. (In Japanese).

Hardening of Steel by Dipping in Fused Cyanide. M. Ishisawa. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 922–929). Experiments on the case-hardening of low-carbon steel by immersion in fused sodium cyanide are described. The hardness and depth of the case, and the carbon and nitrogen contents were measured. The state of their diffusion into the steel was investigated.

The Hardening of Steel by Surface Treatment with Oxy-Acetylene. C. Dehasse. (Revue Universelle des Mines, 1937, vol. 13, June, pp. 237–248). After describing the disadvantages inherent in the normal case-hardening and nitrogen-hardening processes, an account is given of the Shorter process as applied to carbon steels, special steels, and cast irons. Both the structure and the applications of the surface-hardened material are described.

The Mechanism of Nitride-Hardening. M. S. Fisher and Z. Shaw. (Iron and Steel Institute, Sept. 1937 : this Journ. p. 143 P). Two Nitralloy steels were nitrided under various conditions, and the micro-

structure and hardness of the case were investigated. From the results the following conclusions were drawn.

A normally nitrided steel is coated with a " nitride " layer (γ' and ε) about 0·03 mm. thick, below which is a duplex zone consisting of γ' and ferrite, the proportion of the former decreasing from the surface inwards. In pure ammonia the nitride layer forms in a few minutes at 500° C. It is brittle and spalls when severely stressed. The γ'–α aggregate is much less brittle.

The generally-accepted explanation of the hardness of nitrided steel (viz., that it is due to " dispersion " hardening caused by submicroscopic particles of alloy nitrides in α-iron) accounts for the main part of the hardening (up to about 850 Vickers) but iron nitride hardened by dispersed alloy nitrides is responsible for the intense hardness close to the surface.

The rate of nitriding is controlled by the rate of diffusion of nitrogen in the steel. The characteristics of the case produced in a given time at a given temperature are largely independent of the composition of the nitriding gas and of the physical condition of the surface of the steel. Once the nitride layer has been formed, the ammonia can be diluted with about 10 times its volume of nitrogen or about one-third of its volume of hydrogen without affecting the efficiency of the process. The hardness of the case is not materially affected by rapid cooling or by ageing at room temperature.

Prolonged annealing of a nitrided steel in nitrogen eliminates the visible nitride, and reduces the surface hardness to about 850. Similar effects are produced more rapidly by heating in hydrogen. The hardness below the surface is raised and the case depth is increased by annealing.

Further Experiments on the Nitrogen-Hardening of High-Chromium and Austenitic Steels. B. Jones. (Iron and Steel Institute, Sept. 1937 : this Journ. p. 169 P). The nitrogen-hardening properties of high-chromium and austenitic steels were examined after treatment of the surfaces by copper-plating and with phosphate reagent. Regular hardening by these methods was obtained. The greatest hardening was produced by nitriding within the range 500–550° C.; a temperature of 600–610° C. is suitable for only the more highly-alloyed materials, such as the heat-resisting steels. Nitriding at a temperature greater than 600–610° C. results in decreased hardness values for all steels, and the increase in case depth is negligible for austenitic steels. X-ray crystal analysis and microscopical examination were carried out on some of the nitrided steels. X-ray diffraction spectra were obtained from the surface and at various depths within the nitrided case to determine its chemical constitution after nitriding at 550° C. The surfaces of the ingot iron, 8% nickel steel, and 13% chromium steel show the presence of the ε-phase of the iron-nitrogen system, indicating a nitrogen content of approximately 8–11%. This phase is not revealed in the austenitic steels.

The surface layer of the 18/8 chromium-nickel steel consists of the γ' Fe_4N phase, together with chromium nitride, CrN. No evidence was obtained for the formation of a nitride of nickel in any of the steels examined, but, in the austenitic steels, nickel is probably dissolved in the nitrides formed, by a replacement of the metal atoms. The 14/14/2 chromium-nickel-tungsten steel gives lines at the surface which indicate the presence of the γ' nitride phase, corresponding to the composition $(FeCrNi)_4N$. While the spectrum lines obtained from the nitrided ingot iron are well defined and show no distortion, those found in the nitrided high-chromium and austenitic steels are highly diffused. In the steels examined, tests indicate that both the alloy nitride and the crystal lattice of the steel itself are highly distorted, the distortion being so marked as to prevent the formation of a normal spectrum. A change of constitution has occurred in the nitrided 18/8 chromium-nickel steel, as shown by the presence of α-iron lines in the nitrided zone, the atomic lattice being, however, very distorted. The presence of α-iron was not detected in the more stable austenitic alloy, the 14/14/2 chromium-nickel-tungsten steel, but the γ-iron lattice was very distorted, as shown by the very diffused spectrum lines in the zone of greatest hardness.

X-Ray and Microscopic Studies on the Nitrided Layer in Nitriding Steels. G. Hägg. (Jernkontorets Annaler, 1937, vol. 121, pp. 199–217). X-ray studies, microscopic observations and hardness tests on nitrided soft iron, as well as chromium-aluminium and chromium-vanadium steels, have shown the existence of the α, γ', ε and ζ phases of the iron-nitrogen system, and the first three have been identified microscopically in the surface layers of all specimens studied. Some account is given of the mechanism of nitrogen-hardening, and the existence of an unidentified phase near the surface of nitrided chromium-aluminium steel is noted.

Cast Iron Suitable for Nitrogen Hardening. J. E. Hurst. (American Foundrymen's Association, 1937, Preprint No. 37–22). Alloy cast irons suitable for nitrogen-hardening are essentially those containing chromium and aluminium; typical analyses are given, together with mechanical test results on both sand and centrifugal castings. The heat treatment and hardening cycles are examined and discussed, and reference is made to machinability and to methods of preserving surfaces in the unhardened condition when required. Chemical compositions, microstructures and mechanical properties, and typical applications are dealt with.

The Influence of Carbon on the Scaling of Chromium Steels. W. Oertel and W. Landt. (Stahl und Eisen, 1937, vol. 57, July 8, pp. 764–766). Experiments on chromium steels of different carbon contents indicate that resistance to scaling is strongly influenced by composition and by the structure obtaining at the working temperature; austenite is more resistant than ferrite.

WELDING AND CUTTING

(Continued from pp. 142 A–143 A)

Technical Aspects of Oxy-Acetylene Welding. (Engineer, 1937, vol. 163, Apr. 2, p. 395). Correct welding technique and its importance for satisfactory work are discussed. A description is then given of the upward vertical welding methods "A," "B" and "C" which have been successfully employed in the construction of pressure vessels, and have also found application in sheet and plate work. Mention is made of the welding of copper and copper alloys, and of nickel and nickel alloys.

Technical Specifications Relating to Covered Electrodes for the Electric Arc Welding of Current Steels Characterised Solely by their Mechanical Properties. (Revue de la Soudure Autogène, 1937, vol. 29, June, pp. 122–123). These specifications have been drawn up by the Arc-Welding Section of the French Syndical Chamber, and, when passed by the Committee on the Standardisation of Welding, will come into force in France. The dimensions of the wires and rods, the classification of electrodes according to the mechanical properties of the weld metal, the marking and packing of electrodes, &c., are dealt with.

Health and Safety of Gas and Arc Welders. A. Leroy. (Bulletin de l'Association des Industriels de France contre les Accidents du Travail: Revue de la Soudure Autogène, 1937, vol. 29, July, pp. 147–149). Pollution of the surrounding air is likely to occur during welding operations or flame-cutting processes due to gases evolved from the flame or arc, including oxides of nitrogen, to vapours evolved from the metals or alloys being welded, including manganese and chromium from alloy steels, and to fumes derived from protective coatings such as paint. The precautions to be taken are indicated.

The Welding of Non-Alloy Steels with Varying High Carbon Contents. H. Aysslinger. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1937, vol. 5, June, pp. 112–123). It is shown that by the choice of a suitable electrode it is possible to produce welds in steels containing up to 0·6% of carbon, which give tensile and impact values approximating to those of the unwelded material, although the angle of bend of a steel with 0·56% of carbon is considerably lower in the welded than in the unwelded condition. Care is necessary in making fillet welds in high carbon steels with heavy unsheathed electrodes, as hot-tears are likely to occur. With carbon steels of 0·3% of carbon and over, all the precautions for mild steels must be applied.

The Construction and Repair of Locomotive Cylinders by Welding. G. Augereau. (Bulletin de la Société des Ingénieurs Soudeurs,

1937, vol. 8, Mar.–Apr., pp. 2733–2760). An illustrated description of the construction and repair of locomotive cylinders by welding.

Some Suggestions on the Possibilities of the Application of Autogenous Welding in the Foundry. R. Granjon and H. Gerbeaux. (Revue de la Soudure Autogène, 1937, vol. 29, June, pp. 124–127). The authors discuss the application of welding to the construction of plant used in the foundry and also to the making of articles that can be produced by casting.

The Repairing of Grey Iron Castings. R. Meslier. (Revue de la Soudure Autogène, 1937, vol. 29, July, pp. 152–153). A general description is given of the technique of gas and arc welding of broken castings in grey iron, accompanied by details of particular cases in which repairs have been effected by such means.

Weldability of Drill Steels. D. Séférian. (Revue de la Soudure Autogène, 1937, vol. 29, June, pp. 128–135). The author presents a study of the weldability of the types of steels used in making drills such as are used in the petroleum industry, to determine whether welding can be used in the making or repair of such drills. The steel contained 0·41% of carbon, 0·94% of manganese, 0·25% of silicon, and low sulphur and phosphorus contents. He concludes that such drills can be repaired by oxy-acetylene welding without previous heat treatment; after welding, annealing at about 900° C. is necessary. He makes recommendations regarding the filler metal to be used in making the welds. The fractures in these drills are due to the cold-working effect of the percussion tool, to which is added the wear of the metal by friction.

Oxy-Acetylene Welding and Cutting as Applied to Trackwork. N. W. Swinnerton. (Institute of Welding: Welding Industry, 1937, vol. 5, June, pp. 180–188). The author indicates some of the uses to which oxy-acetylene is put in connection with new work and in track-maintenance. The applications are largely in connection with the installation and upkeep of electric trackwork, reconditioning of crossings, and cutting up of scrap rail. An account of the equipment necessary for each type of work is given, and the handling of the flame is discussed.

Welded Steel in High Speed Railroad Service. E. Chapman. (American Society of Mechanical Engineers, May, 1937: Welding Journal, 1937, vol. 16, July, pp. 8–12: Iron Age, 1937, vol. 139, June 24, pp. 50–51). The author examines the practical aspects of designing welded structures, and of the production of welded components, paying particular attention to the cause and avoidance of thermal stresses.

Welding Design and Practice. J. F. Lincoln. (Institute of Welding, June 10, 1937: Welding Industry, 1937, vol. 5, July, pp. 215–220). The replacement of cast and riveted steel in the production of machinery, engineering equipment and building structures by arc welded steel is noted, and the properties of the

shielded and unshielded arc illustrated and discussed. Problems of re-designing and future possibilities of welding are dealt with.

Shrinkage Distortion in Welding. A Review of Literature to January 1, 1937. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, July, Supplement, pp. 29–39). In this report, shrinkage distortion in welding is considered under the following heads :

Butt Welds, Shrinkage Perpendicular to Weld.
Butt Welds, Angular Distortion.
Butt Welds, Shrinkage Parallel to Weld.
Butt Welds, Spacing Allowance.
Fillet Welds.
Tubes.
Beads of Weld Metal.
Shrinkage Distortion in Structural Welding.
Theoretical Aspects.
Practical Methods for Avoiding Distortion.
Bibliography.

An Investigation of Plug and Slot Welds. G. J. Gibson. (Welding Journal, 1937, vol. 16, July, Supplement, pp. 10–21). From his experiments on plug and slot welds, the author concludes that complete face fusion is possible, that the filled plug weld is superior to the fillet plug weld, and that with modern coated electrodes the first is not liable to shrinkage cracks. Certain aspects of mechanical failure are noted in connection with welds of this type, and some details of welding technique are discussed.

On the Residual Stresses in an Arc-Welded Joint. E. Murate. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1096–1107). The author measured the distribution and value of residual stresses in an arc-welded joint, using Heyn's method and a Zeiss optimeter. The residual stresses parallel to the welded line showed maxima at the weld and at the outer ends, the former being in tension, the latter in compression. Perpendicular to the weld line, stress maxima occurred at both ends and in the middle of the weld line, the former being in compression and the latter in tension. Plastic deformation induced by welding was parallel to the weld line, and caused contraction at the welded part and elongation at both ends.

PROPERTIES AND TESTS

(Continued from pp. 149 A–158 A)

An Improved Method for Preparing Cast Iron Transverse Test Bars. A. I. Krynitsky and C. M. Saeger. (American Foundrymen's Association, 1937, Preprint No. 37–5). (*See* Journ. I. and S.I., 1936, No. II., p. 168 A).

The Determination of Elastic Constants by Means of Vibrations of Supersonic Frequency. L. Bergmann. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, July 24, pp. 878–882). By means of vibrations of supersonic frequencies, elastic constants may be determined with greater care and accuracy than by the earlier static methods, and, furthermore, may all be derived from a single specimen. No special forms of test-piece are required, and the method is free from elastic secondary effects which tend to disturb results obtained by static methods.

Concerning the Upper and Lower Yield Points. W. Späth. (Metallwirtschaft, 1937, vol. 16, July 9, pp. 697–701). After reviewing the work of a number of previous investigators, the author describes research in which the influence of elastic reaction in the testing machine was determined, and from the data obtained accounts for the existence of an upper and a lower yield point.

Influence of the Elastic Properties of the Testing Machine on the Formation of the Yield Point in Tensile Tests. E. Siebel and S. Schwaigerer. (Metallwirtschaft, 1937, vol. 16, July 9, pp. 701–702). The author discusses the observations of Welter and Späth on the influence of the elastic properties of the testing machine on the yield point, and describes experiments on mild steel in which upper and lower yield points are obtained independently of this factor, although he indicates that such a factor does influence the interval between the two points.

Law of Similarity in Impact Test-Piece. R. Yamada and Y. Matuoka. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1031–1040). The law of similarity between the Charpy impact test-piece and the Mesnager notch was investigated, and it is shown that the absorbed energy E is represented by :

$$E = cbh^2$$

with a notch of constant radius, where b is the breadth and h the height at the bottom of the notch of a test-piece. The impact value of a material is represented by c, which is equal to E/bh^2, in kg./cm.^{3}; this value is independent of the dimensions of the test-piece. The formula may be applied to sorbitic steels.

The Optical-Polarisation Film Method of Measuring the Surface Stress in Stressed Structures Without a Model. G. Oppel. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, July 3, pp. 803–804). A film of cellulose, resin or similar transparent material which becomes optically active under the effect of stress is applied to the polished or silver-plated surface of the structural part to be examined. The article is then examined under polarised light; on the application of stress, the film becomes optically active and the intensity and direction of the surface stresses are shown up in exactly the same way as in the usual method using transparent models.

On an Approximate Method for Determination of Stress Distribution in Machine Parts by Means of Creep of Metals. E. Takahashi. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1069–1077). To determine the stress distribution in a component, it is modelled in a soft metal and subjected to external forces simulating working conditions for a definite period. Permanent strain due to creep is measured in various parts of the model and percentage deformations are calculated. From known creep data on the particular soft metal used, the intensity of stresses acting on different parts of the model can be estimated.

The Development of a Fatigue Testing Method for Springs and Spring Wire. R. R. Tatnall. (Wire and Wire Products, 1937, vol. 12, June, pp. 297–301). After a preliminary discussion on fatigue phenomena and testing methods and on previous work on wire fatigue, the author describes a machine developed by himself for testing a number of extension springs each under a different loading. It consists of a 12-throw crankshaft with connecting rods attached to slides, the spring being attached to the frame at one end and the moving slide at the other. Methods of calculating the stress, and results obtained are given.

Fatigue Fracture and Brittle Fracture. A. Smekal. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 47–56). The author shows that the dual nature of the fractured surface of brittle materials broken in tension and of plastic materials which have failed by fatigue is due to a change in the mechanism of fracture provoked by the weakening of the cross-section of the test-piece by the process of stressing in tension. The flat part of the broken surface is conditioned by the presence of one definite flaw in the material; the remainder of the fracture results from the effect of a large number of flaws in the body of the test-piece.

On the Fatigue of Metals and the Internal Friction. Y. Kidani. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1050–1055). To ascertain whether fatigue phenomena observed in a metal test-bar may be explained by regarding it as a crystal-aggregate, annealed

specimens of 0·6, 0·3 and 0·1% carbon steels, and copper were tested under constant alternating torque up to the plastic range in a Kuraishi and Kuno testing machine. Hardening and fatigue effects are shown to occur in succession, the transition point coinciding with the commencement of fatigue in the crystallites. The damping rate gave significant information as to the degree of fatigue. Certain aspects of fatigue in copper are also noted.

On Some Questions in the Study of Fatigue of Metals. Y. Asakawa and S. Fudita. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1056–1059). The effect of fatigue phenomena on the mechanical properties of a 0·3% carbon steel is observed, and it is concluded that the nature of the fatigue limit is somewhat vague. The progress of fatigue is discussed, and it is shown that this may be indicated by the fatigue limit.

Impact- and Static-Torsion and Bending Diagrams of Fatigued Metals. M. Itihara. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1041–1049). From a comparison of the impact and static torsion diagrams of fatigued 0·2% carbon steel, and of impact and static bending diagrams of the same steel, it is concluded that impact values or total deflection of torsion or bending diagrams decreases in three stages owing to fatigue; static values decrease linearly however. The degree of fatigue may be deduced from static or impact tests, but the former are more reliable.

A Simplified View of the Hardening of Steel and of the Transition Constituents. A. Sauveur. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 815–828). The author expresses his views on the hardening of steel and on the transition constituents by the demonstration of the following propositions: (1) Regardless of treatment of any kind, all iron-carbon alloys consist of aggregates of ferrite and cementite. Residual austenite is ignored; (2) The properties capable of being imparted to any given iron-carbon alloy depend on the grain size of the ferrite and the particle size of the cementite after treatment; (3) For a given carbon content, hardness increases and ductility decreases with decreasing particle size of the cementite; (4) For a given carbon content, hardness increases and ductility decreases with decreasing size of ferrite grains.

Determination of the Magnification Required in Measuring Vickers' Indentations. K. Sporkert. (Zeitschrift für Metallkunde, 1937, vol. 29, May, pp. 168–170). By means of measurements made with an eyepiece micrometer of a Vickers' indentation on a polished surface, it is shown that accuracy is proportional to magnification only up to 50 dia.; increased magnification gives only a small increase in accuracy, hence for direct ocular measurement a magnification of 50 dia. is recommended.

Theoretical Points of View on Age Hardening. C. Benedicks.

(Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 686–693). The author summarises theoretical conceptions of age-hardening and concludes that in a quenched solid solution no crystal nuclei need be present, but on ageing at a given temperature they are formed, hence considerably stronger effective supersaturation than previously existed is conditioned, and hardness and electrical resistivity are increased. Where more than two components are present the formation of crystal nuclei will play an increasingly important rôle. Previous discrepancies in observed phenomena are explained on the basis of this argument.

Temper-Brittleness in Steels. L. Guillet and M. Ballay. (Académie des Sciences, June 21, 1937 : Génie Civil, 1937, vol. 111, July 10, pp. 45–46). A brief account is given of the conditions of tempering tending to produce temper-brittleness, followed by a more detailed examination of the occurrence and mechanism of the process. Hardness and impact values are given for steels of the following compositions :

C. %.	S. %.	P. %.	Mn. %.	Si. %.	Ni. %.	Cr. %.	Mo. %.	Al. %.
0·36	0·002	0·015	0·45	0·21	3·7	0·86	0·23	...
0·30	0·005	0·010	0·32	0·10	3·15	0·70	0·04	...
0·21	...	...	0·59	0·31	2·77	1·13	0·44	0·95

These steels were oil-quenched from 850° C., 850° C. and 900° C., respectively, and tempered at 200° and 400° C., 650° C. and 660° C., respectively. Reference is made to the influence of the aluminium in the last steel.

Temper-Brittleness of Steels. K. Nagasawa. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1078–1087). The characteristics of temper-brittleness were examined on about 200 charges of carbon and alloy steels. The results led to the defining of two kinds of temper-brittleness, one observable at the tempering range 450–525° C., showing decreased impact value but unaffected by the cooling rate from the tempering temperature, and the other observed above 525° C. and exhibiting a great difference in impact value on slow and rapid cooling. These are designated as " first " and " second " temper-brittleness respectively. The cause of temper-brittleness is explained in the first case by the precipitation of some carbide from the martensite, the precipitated carbide remaining as such in the specimens which are slowly cooled from a temperature above 525° C. and giving rise to the " second " temper-brittleness, or remaining dissolved in the α-iron in a rapidly cooled specimen and hence giving a higher impact value for tempering temperatures above 525° C.

Some Experiences with Wear Testing. P. S. Lane. (American Foundrymen's Association, 1937, Preprint No. 37–1). The author reviews difficulties associated with the testing of wear and goes on

to describe a successful machine employed by the Koppers Company, American Hammered Piston Ring Division, for conducting such tests. Good and poor irons for use in steam service are dealt with, and the effects of heat treatment on a 1·25% nickel, 0·40% chromium iron discussed. Experiments on the wear resistance of auto and aero piston rings are described, together with those on rings made of a combination of bronze and cast iron. The effects of composition and structure on wear resistance are examined.

On a Method of Preventing Abrasion Caused by the Sliding Friction between Steels without Using Lubricant. S. Saito. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1060–1068). The wear by dry abrasion which occurs when sliding contact takes place between two steel surfaces is decreased by the simultaneous action of a softer, non-greasy material also engaged in sliding contact on the same surface. The author has measured the wear occurring in three different cases using carbon rod, soft cast iron, teak and ebonite, tungsten carbide powder, aluminium powder, tungsten powder, coal tar, and a dry film of pitch in benzol, as the soft component, and has investigated the phenomenon.

Wear Tests on Ferrous Alloys. O. W. Ellis. (Institute of British Foundrymen, June, 1937 : Foundry Trade Journal, 1937, vol. 57, July 8, pp. 23–26, 29). The author examines the abrasion-resistance of alloy steels including chromium and nickel steels, and of austenitic, pearlitic and white irons, to the action of silicon carbide, primary bowl sands, silica, feldspar, marble, talc and granite. Ni-Hard and stellite were also examined for abrasion-resistance. The data obtained are tabulated and the results critically discussed.

The Relation of Ball Wear to Power in Grinding. F. D. De Vaney and W. H. Coghill. (Engineering and Mining Journal, 1937, vol. 138, July, pp. 337–340). It is shown that ball wear is independent of ball size for equal loads, and independent of speed for equal power input.

Peculiar Effects in the Magnetic Testing of Materials. O. Holtschmidt. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, July, 17, pp. 862–864). In the magnetic testing of materials, defects, which give rise to irregularities in the magnetic field, are made visible by the application of iron powder. The indications of the method, however, are not always unequivocal, because, under certain conditions, irregularities in the magnetic field may be set up by other causes. Thus, it is shown that the iron powder may collect at cold-worked spots in just the same way as it does in the neighbourhood of defects.

Mechanical Properties of Rope Wire in the Temperature Range from + 20° to − 50°. A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 7, pp. 97–103). The authors have investigated the tensile properties, and the ability to undergo to-and-fro bending and twist-

ing of three soft and twelve hard patented drawn steel wires, in the temperature range from + 20° to — 50° C. The carbon contents of the soft wires varied from 0·02 to 0·28%, those of the hard wires from 0·41 to 0·77%; two of the soft wires contained only traces of silicon and about 0·31% of manganese, while the other soft and all the hard wires contained approximately 0·18% of silicon and 0·6–0·7% of manganese. The test results are set out in a table and in graphs; micrographs are also reproduced. With all the wires, the tensile strength increased as the testing temperature was lowered, but the elongation and reduction of area remained practically unchanged. Minimum ability to withstand bending to and fro and twisting was found at — 20° C.

Effect of Composition and Heat Treatment on Properties of Steels for Low Temperature Service. J. W. Sands. (Industrial Heating, 1937, vol. 4, June, pp. 448–452, 496–497, 510). An account of the embrittlement phenomena associated with the use of steel at low temperatures and means of counteracting or overcoming them. The effects of carbon and nickel are dealt with, and some austenitic steels are recommended. Results of tensile tests on certain steels are given, and the anomalous behaviour of Hadfield's manganese steel is noted.

Absorption and Evolution of Hydrogen in Iron and Steel. F. Philstrand. (Jernkontorets Annaler, 1937, vol. 121, pp. 219–230). Under conditions similar to those employed by Sieverts and others, a rapid absorption and evolution of hydrogen in iron has been noted by the author. The addition of 1% of carbon or 1% of manganese does not affect the solubility, which is, however, perceptibly decreased in the presence of 4% of silicon. An account is given of processes by which hydrogen is lost.

Grey Cast Iron. S. Tour. (Iron Age, 1937, vol. 139, June 24, pp. 40–43). The evolution of cast iron as a dependable engineering material is described. Some account is given of malleable iron, steel castings, and non-ferrous foundry alloys.

The Growth of Grey Cast Iron. H. Sawamura. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 896–908). Six types of commercial grey iron were repeatedly heated and cooled in a special gas dilatometer which could be highly evacuated in order to test the influence of atmospheric conditions on the increase of volume at the Ar transformation point. On the first cooling it was greatest *in vacuo*, and in nitrogen and carbon monoxide was greater than in air. In hydrogen it was very small. Growth of the lower silicon irons after six heatings and coolings was of the same order as that reported above, but abnormal results were obtained in nitrogen. Irons containing 2·11% of silicon grew less *in vacuo* than in carbon monoxide. The results are attributed to the effect of the surrounding atmosphere on graphitisation.

The Growth of Grey Cast Iron (Second Report). H. Sawamura. (Memoirs of the College of Engineering, Kyoto Imperial University,

1937, vol. 9, March, pp. 216–221). The author continues his investigation of the influence of ammonia, methane, and water vapour contained in hydrogen or nitrogen upon the growth of grey cast iron subjected to repeated heating and cooling between 600 and 900° C. The expansion at the Ar transformation on the first cooling, and the influence of various atmospheric conditions upon the graphitisation of the pearlite-cementite, were examined, and it was concluded that the abnormal expansion observed must be due to pearlite-cementite graphitisation as suggested by Benedicks and Löfquist.

The Hardenability of Cast Iron. D. W. Murphy and W. P. Wood. (American Foundrymen's Association, 1937, Preprint No. 37–18). Data from five heats are presented to illustrate the use of aluminium additions to molten iron to confer shallow hardening properties. The optimum addition seems to be from 0·02 to 0·03%, while figures in excess of this confer deep-hardening properties. Melting practice prior to de-oxidising must be controlled if the reduction of hardening resulting from a given addition of aluminium is to reach a maximum. The aluminium does not appear to affect the amount or distribution of the graphite, but, as cast, treated irons appear to show more pearlite in a very fine form than the untreated irons. Shallow-hardening irons exhibit, it appears, a finer network structure than deep-hardening irons, but chemical analysis does not suffice to distinguish them, and methods for developing austenitic grain size are not sufficiently advanced to permit of a detailed report. The author concludes with a survey of the mechanical properties of the shallow-hardening irons.

Influence of Composition and Section Size on the Strength-Hardness Ratio in Cast Iron. A. L. Boegehold. (American Foundrymen's Association, 1937, Preprint No. 37–25, pp. 1–27). After a preliminary examination of composition, hardness, strength and structural appearance of the micro-constituents of cast irons, the author investigates in more detail the effect of carbon and silicon and cooling rate upon the structure and hardness of the iron. The ternary eutectic steadite is briefly dealt with, and the general effects of composition and cooling rate upon the strength-hardness ratio are then analysed.

Microstructure and Physical Properties of Alloy Cast Irons. V. A. Crosby. (American Foundrymen's Association, 1937, Preprint No. 37–25, pp. 28–52). The author notes the common alloying additions made to cast irons and comments briefly on their merits as carbide forming elements or as graphitising agents. A detailed examination is then made of the effects of the alloy additions upon the structure and mechanical properties of the iron.

The Thermal Characteristics of Black Heart Malleable Cast Iron T. Kikuta. (Science Reports of the Tôhoku Imperial University 1936, Oct., Professor K. Honda Anniversary Volume, pp. 909–921). The author deals with the effects of heat treatment upon the impact value of black heart malleable cast iron, and of the initial cooling

temperature upon embrittlement after complete graphitisation. Impact tests at various temperatures, and measurements of electrical resistivity during heating and cooling were carried out, and theoretical considerations on the embrittlement of the material discussed.

Properties of Fully Annealed and Heat Treated Malleable Irons. R. Schneidewind and A. E. White. (American Foundrymen's Association, 1937, Preprint No. 37–21). The author shows that although varying somewhat in their different rates of cementite breakdown, three quick-anneal white irons purchased on analyses gave fair results on malleablising, torsion figures being, however, rather unfavourable due to the presence of temper carbon. The microstructure of the treated irons is investigated.

"Ni-Resist" in Great Britain. A. B. Everest. (International Foundry Congress, Paris, 1937: Foundry Trade Journal, 1937, vol. 57, July 8, pp. 27–29). The author gives details of some of the more outstanding applications of the austenitic cast iron "Ni-Resist" in British engineering practice. The composition and production of the material in this country are described, and its properties, particularly in regard to corrosion and erosion resistance, discussed in detail in respect of industrial applications. Other physical properties such as resistivity and non-magnetic qualities are also dealt with.

Some Special Cast Irons of Interest in Chemical Engineering. A. B. Everest. (Chemistry and Industry, 1937, vol. 56, July 17, pp. 657–666). The author discusses the properties and limitations of cast iron, and the development and applications of low alloy cast irons and of the highly alloyed austenitic irons with particular note of the corrosion-resisting properties of Ni-Resist.

Cast Crankshafts. H. J. Gough. (Institution of Automobile Engineers, Mar. 23, 1937: Engineer, 1937, vol. 163, Mar. 26, pp. 360–361). The author describes investigations on five commercial materials employed for cast crankshafts; these comprise an alloy steel, a copper-chromium iron, an inoculated iron, a chromium-molybdenum iron, and a nickel-chromium iron. Tabulated data on mechanical tests and chemical analyses, together with a comparison of fatigue resistances, are given.

Drilling Oil Wells Two Miles Deep. (Nickel Bulletin, 1937, vol. 10, July, pp. 150–152). The high stresses encountered in drilling have led to the use of nickel-chromium steels both with and without molybdenum in oil-well equipment. A table is given showing the requirements and uses of nickel steels in oil-drilling equipment.

Moulded Pipes, Their Stressing, Strength, and the Raising of Their Working Pressure. W. Boček. (Giesserei, 1937, vol. 24, June 4, pp. 293–299; July 2, pp. 344–348). The author discusses the design of moulded cast-iron pressure pipes of various shapes (curved, branched, &c.), the stresses occurring in them, their strength properties and means for increasing their resistance to the pressures that may be put on them in service.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 159 A–161 A)

Primary Etching of Grey Cast Iron. H. Jurish. (Giesserei, 1937, vol. 24, July 2, pp. 341–343). The author gives two generally applicable etching reagents for the development of the primary structure of grey cast iron, namely, concentrated sulphuric acid plus formic acid, and concentrated sulphuric acid plus boric acid. These reagents are particularly useful in cases where the primary structure of cast iron and also of malleable cast iron is not revealed by the usual solutions. The effect of these reagents is illustrated in a number of microsections.

X-Ray Field Inspection of Welded Seams in Pressure Piping. H. R. Isenburger. (Welder, 1937, vol. 9, June, pp. 165–167, 173). Describes the advantages and purpose of examining welds in steam pipes by X-rays.

Ferrite—Its Occurrence and Control in Grey Cast Iron. R. H. Bancroft and A. H. Dierker. (American Foundrymen's Association, 1937, Preprint No. 37–9). Ferrite is normally considered as associated with a low cooling rate, a high-silicon content, a high-carbon content, or a combination of these factors. Nevertheless, the authors found in very light section castings of subnormal carbon content, ferrite areas which vanished on raising the carbon. As a result of investigations to determine the rôle of carbon, it was shown that any given iron exhibits a definite cooling rate which will produce a normal pearlitic structure, while rates above or below this optimum level produce other types of ferrite classed by the authors as primary and secondary ferrites.

Graphitisation and Inclusion in Grey Iron. J. W. Bolton. (American Foundrymen's Association, 1937, Preprint No. 37–26). The first part of the paper deals with problems relative to the graphitisation of cast iron. The tendency of alloys to approach structural stability is noted and the implications of this in regard to cast iron, which is normally unstable, are discussed. Comparisons are drawn between the behaviour of carbon in hyper- and hypo-eutectic cast irons, and the stability of the eutectic carbide in the latter noted as a possibility. The microstructure of grey irons is treated in detail, and the origin of the graphite examined in the light of heating and cooling curves. The effect of pouring temperature upon structure and strength is shown, and the apparent anomalies in behaviour of cast irons of a given composition re-examined and discussed.

X-Ray Investigation of Tempered Martensite in Carbon Steels. Z. Nishiyama. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 840–

849). To reveal the nature of tempered martensite, its lattice constant and the breadth of the lines of its X-ray diffraction pattern were measured. Five lines were examined, 110, 200, 211, 220 and 310. The results obtained were in favour of the solid solution theory regarding β martensite.

A Special Structure of Cementite Separated from Austenite. A. Hultgren and O. Edström. (Jernkontorets Annaler, 1937, vol. 121, pp. 163–175. On cooling iron alloys fairly rapidly from high temperatures, the carbon content being high and silicon above 0·2%, the cementite separating from the austenite is not homogeneous, but contains fine points, threads or lamellæ which darken on etching. This has not been observed when only traces of silicon are present, even when accompanied by 0·50% of manganese. A homogeneous structure is produced by slow cooling. The phenomenon has been observed in malleable castings and steel.

The Structure of Eutectic Alloys and its Alteration on Rolling and Heating. G. Tammann and H. Hartmann. (Zeitschrift für Metallkunde, 1937, vol. 29, May, pp. 141–144). An explanation of the fundamentals of eutectic formation. The rolling capacity of eutectic alloys is tested, and the structural alterations which result from such treatment are followed. The work is carried out on an alloy of bismuth, cadmium, lead, and tin; on similar alloys in the absence of any one of these elements, and on an alloy containing cadmium, tin, and zinc.

Effect of Reversed Deformation on Recrystallisation. P. A. Beck. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 818; Metals Technology, 1937, vol. 4, June, No. 4). From the author's work it is concluded that there is no direct physical relation between hardening and recrystallisation, and that further investigation on the effect of inverse deformation is required. Consumptibility is decreased by inverse deformation for all orientations and deformation values examined. The contradiction between the work of Polanyi and Schmid and that of van Arkel and Ploos van Amstel is discussed, and it is shown that there is no real difference between the views of Polanyi and Burgers.

Primary Crystallisation of Metals. F. R. Hensel. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 803; Metals Technology, 1937, vol. 4, June, No. 4). An account of investigations into the laws governing the formation of the primary crystal structure during solidification. Experiments were carried out on chill castings of tin and zinc, but the results obtained have enabled conclusions to be drawn as to sand castings.

On the Determination of the Grain Size of the Fine Crystalline Powder. M. Yamada, Y. Abe and I. Tesima. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 66–71). The influence of lattice distortion in crystal grains upon the breadth of the Debye-Hull lines is discussed. The work is applicable to metals.

The Influence of Impurities on the Grain Size of Iron. G. Wassermann. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, July, pp. 55–58). The coarse structure associated with the recrystallisation of electrolytic iron is to be attributed to the extremely small number of nuclei formed during the γ-α transformation, and is to be regarded as an indication of the extreme purity of the electrolytic iron. Recrystallisation in atmospheres of hydrogen and nitrogen, for example, which are soluble in iron at high temperatures, yields quite a fine-grained structure; this effect is manifested even at low gas pressures, and a predetermined grain size may be obtained by controlling the gas pressure. The fine structure of recrystallised carbonyl or Armco iron, noted even when the process is conducted *in vacuo*, is conditioned by the presence of small amounts of oxygen, nitrogen, carbon, and similar impurities initially present in the iron; by annealing at high temperature in hydrogen, such impurities may be so far removed that these irons comport themselves like the electrolytic metal. The relationship between purity, grain size, and magnetic properties is discussed.

The Transformation of Austenite. E. C. Bain. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 829–839). The products of the direct transformation of austenite in medium and high carbon steel are characteristic for the temperature of actual transformation :

Transformation Range.	Product.
Near A_1	Coarse lamellæ.
Just above about 550–500° C. .	Fine lamellæ.
Below about 550–500° C., but above about 150° C. . . .	Black-etching acicular ferrite-carbide aggregate.
Below about 150° C. . . .	Martensite.

The division between the third and fourth items of the table is not sharp unless the distinction between tetragonal and cubic martensite is regarded as a criterion. The etching characteristics change gradually in the products formed in the range 250° C. to 100° C.

Transformations in Metals and Their Uses. P. D. Merica. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 636–651). The author discusses generally the nature of transformations in the solid state and their effect on the physical properties of metals. After dealing with suppressed transformations and intermediate stages, and with suppressed partial lattice transformations, he considers in more detail the "age-hardening" alloy systems. Difficulties associated with age-hardening are described, reference being made to temper-brittleness in steels and to corrosion embrittlement in stainless steels. He concludes with the theory and causes of age- and precipitation-hardening.

Characteristics of Transformations in Solid Phases. G. Borelius. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 129–135). A discussion and analysis is presented of the mechanism of order-disorder transformations in metallic alloys, and of the transformations observed in certain chemically homogeneous substances, mostly at low temperatures. The magnetic transformation of ferromagnetic metals is referred to.

On the Relation Between Diffusion and Transformation Point of Metals. T. Kase. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 670–676). The author describes the results of an investigation of the diffusion of metallic elements and of non-metals into metals. Metals investigated included nickel and iron, zinc and carbon being diffused into the latter. Curves showing the relationship between the logarithm of the increase in weight of the specimen and the reciprocal of the corresponding absolute temperature exhibit the presence of a transformation point or the melting point of the specimen or of the material diffused into it.

Constitution of High-Purity Iron-Carbon Alloys. R. F. Mehl and C. Wells. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 798 : Metals Technology, 1937, vol. 4, June, No. 4). A series of high-purity iron-carbon alloys ranging from 0 to 1·4% of carbon was prepared from hydrogen purified carbonyl iron carburised in dipentene-hydrogen and dipentene-benzene-hydrogen. The technique of preparing homogeneous alloys of any desired carbon content is described. The Ar_3, Ac_3, Ar_1, Ac_1, Ac_{cm}, and Ar_{cm} points of the alloys were determined by dilatometric, thermal, magnetic, and microscopic methods. The effect of carbon on the degrees of superheating and supercooling is discussed. No evidence was found of the Curie point in the austenite field. Ideal dilatometric curves are calculated and compared to experimental curves; causes of deviation are discussed.

Magnetically Hard, Low-Carbon Nickel-Copper Steels. H. Legat. (Metallwirtschaft, 1937, vol. 16, July 23, pp. 743–748). By examining the microstructures the boundary lines of the Fe–Cu miscibility gap in the iron corner of the ternary Fe–Ni–Cu system, with up to 25% of copper and nickel, at room temperature and 1250° C. were determined. Steels falling within this field were subjected to a precipitation-hardening heat treatment, and the remanence and coercive force were measured. At 15% nickel and 15% copper the maximum of a high range of coercive force, the axis of which ran from 18% nickel, 0% copper to 13·5% nickel, 25% copper, was found; the maximum reached was 300 oersted, the corresponding remanence being 1500 gauss. Attempts to improve the best composition by alloying with carbon, silicon, manganese, cobalt, molybdenum, tungsten, vanadium, titanium, tantalum, zirconium, silver, antimony, bismuth, chromium, &c., failed, because the great

magnetic hardness of these steels depends on the combined effect of two hardening processes, namely, the precipitation of copper and the austenite-martensite transformation. It was not possible to strengthen the effect of one of these processes without weakening that of the other and so producing a worse total effect. The demagnetisation curves of two experimental melts are compared with those of known magnet steels.

Some Alloys for Use at High Temperatures. Part IV.—The Constitution of the Alloys of Nickel, Chromium and Iron. C. H. M. Jenkins, E. H. Bucknall, C. R. Austin and G. A. Mellor. (Iron and Steel Institute, Sept., 1937 : this Journ. p. 187 P). The paper consists of a description of the work carried out at the National Physical Laboratory on the constitution of the alloys of nickel, chromium and iron, together with a review of the literature up to September, 1936. For convenience, the paper is divided into four sections relating to (*a*) chromium-iron alloys, (*b*) nickel-iron alloys, (*c*) nickel-chromium alloys and (*d*) nickel-chromium-iron alloys. New experimental work is described in Sections B, C and D. This comprises a determination of the solidus of the nickel-iron system, reinvestigations of the liquidus and solidus temperatures and solid constitution, *at temperatures above* 800° C., of the nickel-chromium alloys and of the nickel-chromium-iron alloys containing up to 50% of chromium. The phase diagram of the ternary alloys is illustrated by horizontal sections.

Solubilities of Hydrogen in Binary Alloys in Relation to their Equilibrium Diagrams. M. Fukusima and S. Mitui. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 940–948). The solubility of hydrogen in binary alloys, the equilibrium diagrams of which are of simple and typical types, such as a single solid solution (copper-nickel), or two series of solid solutions (cobalt-iron), or a mixture of two saturated solid solutions (cobalt-copper), or of two phases lying between compounds (nickel-antimony), were measured, and the results explained with the aid of the diagrams.

The Crystal Structure and the Composition of the Intermediate Iron-Tungsten and Iron-Molybdenum Phases. A. Westgren. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 852–863). The crystal structure of the intermediate phases present in the iron-tungsten and iron-molybdenum systems has been determined by means of Arnfelt's X-ray data. The unit cell of the hexagonal phase Fe_2W has the dimensions $a = 4{\cdot}727$; $c = 7{\cdot}704$ A.U. The group is defined, together with the arrangement of the 12 atoms in the cell. The phases "Fe_3W_2" and "Fe_3Mo_2" are rhombohedral; the author gives dimensions defining both phases, and points out that as there are 13 atoms in the unit cells, the commonly used formulæ Fe_3W_2 and Fe_3Mo_2 are excluded. It is shown that the formulæ can only be Fe_7W_6 and Fe_7Mo_6, a conclusion

verified by the atomic groupings determined by the author. Technical 85% ferro-tungsten is found to consist of Fe_2W and tungsten, Fe_7W_6 being therefore unstable at low temperatures although its decomposition rate is low. Iron-molybdenum alloys annealed for one month at 500° C. or 600° C. contain no other intermediate phase than Fe_7Mo_6.

The Fe–FeSi-Graphite System. H. Hanemann and H. Jass. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 793–814). The binary eutectic curves of the graphite system which were investigated by the authors run from 4·23% of carbon on the carbon side at 1152° C., to 21·2% of silicon at 1205° C. on the silicon side. These agree, in carbon contents, with Goutermann's values, while those of Honda and Murakami's lie below, and those of Wüst and Petersen's lie considerably higher. The eutectic carbon content is given by the following equation :—

$$\% \text{ C} = 4{\cdot}23 - \frac{\% \text{ Si}}{3{\cdot}2}.$$

The Constitutional Diagram of the Iron/Iron-Sulphide/Manganese-Sulphide/Manganese System. R. Vogel and W. Hotop. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, July, pp. 41–54). The ternary system iron/iron-sulphide/manganese-sulphide/manganese was investigated by thermal and chemical methods and by examination of microstructures. Good agreement was established with the work of Körber, Oelsen, Meyer, and Schulte, and also with that of Wentrup, regarding the expansion of the area of insolubility in the liquid state. Crystallisation phenomena were made clear by exhaustive examination of four sections through the "sulphur corner" of the system. The conditions of crystallisation were determined by the appearance of two maxima of three-phase equilibrium, which, in projection, practically coincided with the iron-manganese sulphide diagonal of the system. The first maximum corresponds to the maximum three-phase equilibrium (at 1600° C.) between a sulphide liquid phase, a metallic solid solution, and a manganese-sulphide/iron-sulphide solid solution. The second maximum corresponds to equilibrium between a eutectic melt, a manganese-sulphide/iron-sulphide solid solution, and an iron-manganese solid solution. Structure is dependent on the position of the alloys with regard to the concentration surface in respect of the maxima. At 1000° C. a eutectic four-phase surface makes its appearance, the ternary eutectic point of which practically coincides with the binary eutectic point of the iron/iron-sulphide system. The limits of concentration for the appearance of free iron sulphide in the structure, and their displacement consequent upon the formation cored crystals, were also determined. For the full understanding of equilibrium conditions, the theoretically necessary course of the δ–γ transformation determining them is illustrated diagrammatically.

CORROSION OF IRON AND STEEL

(Continued from pp. 162 A–163 A)

Iron Oxide Films. H. A. Miley. (Metallurgist, 1937, vol. 11, Apr. 30, pp. 25–28; June 25, pp. 37–38). The author examines the evidence tending to show that the oxide formed on polycrystalline iron when exposed to air at temperatures well below 200° C. is $\gamma - Fe_2O_3$, while that formed above this temperature is $\alpha - Fe_2O_3$ until Fe_3O_4 begins to appear as an underlying layer at temperatures well above 400° C.

Corrosion of Metals. A. Leroy. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, Mar.–Apr., pp. 2708–2729). After a general review of the mechanics of the corrosion of metals, the author discusses various aspects such as the influence of heterogeneity in the metal, non-uniformity in the corroding liquid, the appearance of corroded metals and the consequences of corrosion, the relative influence of various factors in corrosion, the fight against corrosion, and the influence of welding on the corrodibility of metals. Photographs of welded specimens of various steels after corrosion in acid and in sea water are reproduced.

The Corrosion Problem and the Engineer. F. Hudson. (Metallurgia, 1937, vol. 16, June, pp. 51–54). The author outlines aspects of practical significance in connection with loss of metals by corrosion. Particular stress is laid on the attack of iron and steel structures by fresh and salt water.

Corrosion of Cast Iron. M. Tagaya. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 1008–1016). The author has studied the relationship between the corrosion of cast iron and its chemical composition and structure. The effect of impurities in high-carbon, high-silicon and low-carbon, low-silicon irons was investigated. Corrosion tests were conducted in tap water and semi-normal hydrochloric and nitric acids.

Effect of Light on the Corrosion of Steel in Aqueous Solutions. H. Endô and H. Sekiguchi. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 991–1007). Specimens of copper-bearing mild steels were suspended on glass hooks in various aqueous solutions contained in 350 c.c. glass bottles exposed to diffuse sunlight, the bottles being arranged in three rows on a shelf and so giving rise to partial shielding of the second and third rows. The loss of weight in dilute acidic solutions, especially in nitric and acetic acids and in ferric chloride solutions, was greater in the specimens most exposed to light. The mechanism of the acceleration of corrosion of steel in dilute acidic solutions by light is explained.

On the Mechanism of the Dissolution of Iron and Steel in Nitric Acid of Various Concentrations. H. Endô and H. Kawasé. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 969–990). The authors conclude that dissolution of iron and steel in nitric acid occurs by two processes, namely by the electrochemical hydrogen evolution process and by direct chemical attack, the first applying to dilute and the second to concentrated solutions. The formation of reduction products of nitric acid is taken into account, together with that of the complex salt of nitric oxide and ferrous nitrate. Phenomena observed in connection with attack by the concentrated solutions are discussed and elucidated.

Chemical Intercrystalline Fracture of Riveted Joints in Boilers. S. F. Dorey. (Institution of Naval Architects, Mar. 18, 1937 : Engineer, 1937, vol. 163, Apr. 2, p. 390). A description is given of the factors governing caustic embrittlement, followed by an outline of the present position of the problem. Some hitherto unexplained aspects are briefly enumerated, and the use of sodium sulphate in preventing intercrystalline cracking, and the effect of sodium silicate in promoting breakdown, are discussed.

BOOK NOTICES

(Continued from pp. 110 A–116 A)

BRITISH NON-FERROUS METALS RESEARCH ASSOCIATION. Research No. 58. "*Creep of Non-Ferrous Metals and Alloys.*" A Review of Published Information by W. A. Baker. 8vo, pp. 19. London, 1937: The Association. (Price 2s.)

The object of the present publication is to summarise the available published information relating to the creep characteristics of non-ferrous metals and alloys. The data presented have been selected critically, and include information on copper and copper alloys, nickel alloys, aluminium and aluminium alloys, and lead. The numerical values are set out in tabular form convenient for reference, with compositions of materials; each table is followed by a list of papers on which the data are based, with a note on the contents of each paper. An index to all metals and alloys mentioned is supplied.

BURKHARDT, A. "*Zink und seine Legierungen.*" Zusammenfassende Darstellung der Eigenschaften, Heft 1. (Beiträge zur Wirtschaft, Wissenschaft und Technik der Metalle und ihrer Legierungen.) La. 8vo, pp. 40. Illustrated. Berlin, 1937: N.E.M.-Verlag. (Price 5 RM.)

This is the first of a series of publications on metals and alloys published by the N.E.M.-Verlag in Berlin. In the introduction it is stressed that zinc is one of the metals produced in Germany, and that an increased use of the metal is economically desirable. The rapid expansion in the use of zinc alloys for die-castings and other purposes make it likely that technical considerations alone will bring about the increased consumption hoped for. The subject is treated in three sections dealing with the properties of pure zinc, the influence of added metals, and the uses and applications of zinc alloys respectively. The first part covers the physical, chemical, and technological properties of zinc in a detailed manner. Crystal structure, mechanical properties, and corrosion resistance to various media are all dealt with, and the tables of physical constants are very complete. Practical operations, such as melting, rolling, pressing, and soldering, are adequately dealt with at the end of this section. The discussion of the alloys of zinc opens with the consideration of the effect of the normally occurring impurities in commercial zinc, and is followed by a more detailed treatment of the more important binary alloys. Equilibrium diagrams are given for systems mentioned, and there are also many graphs of the variation in properties with composition. This part concludes with a description of the ternary system Zn–Al–Cu, on which is based the majority of the alloys used for die-casting and hot pressing. The last section gives an account of the uses and applications of zinc alloys, and is largely concerned with die-castings and pressings, but bearing metals, solders, and zinc for primary cells are also shortly dealt with. The evolution of the die-casting alloys is described, and the important part played by the introduction of purer qualities of commercial zinc is made clear, particularly with regard to ageing and corrosion. A considerable part of the description of alloys

for pressing is taken up with an account of the volume changes taking place after pressing and the effect of composition on this phenomenon, and graphs are also given showing the effect of composition on the mechanical properties. The book is a valuable condensed review of existing information on the subject, and references are given to nearly four hundred original papers where more detailed information may be sought. STEPHEN L. ROBERTON.

HADDAN, R. "*Patents for Inventions.*" A Concise Guide for Inventors and Patentees. 8vo, pp. viii + 99. London, 1937: Sir Isaac Pitman and Sons, Ltd. (Price 3s. 6d.)

The author has compressed into fifteen chapters a useful survey of the law and practice relating to patents for inventions in England. In the course of over three centuries nothing has been lost in intricacy, and in spite of amendments the employment of the statute is becoming increasingly difficult. Wisely, perhaps, the author does not indicate the profitable loopholes which practical experience sometimes reveals. Chapters XI and XII, dealing with foreign patents, are likely to prove sources of assistance and comfort to those whose interests extend beyond this country; no attempt has been made, of course, to discuss the finer details of foreign patent law. An excellent index completes the book.

INTERNATIONAL CONGRESS OF ACETYLENE, OXY-ACETYLENE WELDING AND ALLIED INDUSTRIES, London, 1936. "*Proceedings.*" La. 8vo. In six volumes. pp. 1566. Illustrated. London, 1937: British Acetylene Association. (Price £2 2s.)

The Twelfth International Congress of Acetylene, Oxy-Acetylene Welding and Allied Industries was held in London in June 1936 under the Presidency of J. Donald Pollock. The Proceedings, which have now been issued in six volumes, contain five general reports and seventy-four papers, each of which has been written by a recognised authority. They deal exhaustively with the results of the latest research in welding, cutting, surface-hardening, metal spraying and other important applications of the oxy-acetylene process. Every paper has been translated in full into English, when this was not the language of origin.

The papers are accompanied by summaries in English, French and German, and in the case of those which were read at sessions of the Congress, a complete summary of any discussion is also included.

KRUSCH, P. "*Die Metallischen Rohstoffe ihre Lagerungsverhältnisse und ihre wirtschaftliche Bedeutung.*" 1 Heft. "*Vanadium, Uran, Radium.*" 8vo, pp. viii + 148. Stuttgart, 1937: Ferdinand Enke Verlag. (Price 10 marks.)

This is the first of a series of fifteen volumes to be published surveying the present world position of metals as regards ore distribution, production, and market conditions. The author deplores the absence in Germany of any publications akin to the periodical *Economic Geology* in the United States or the geological monographs of our own Imperial Institute, and he considers it a necessary preliminary to the success of the recently instituted Four-Year Plan in Germany that a

reliable survey of world conditions in metal production should be available. The present volume deals with vanadium, radium and uranium, the last two being considered together, the book therefore being divided into two main sections. For each of the metals there is a very short historical account of its discovery and isolation, and some indication is given of the principal chemical properties. The occurrence of the metals in nature is given in some detail, and the composition and some of the physical properties of the more important ores are tabulated. The major portion of the volume is taken up with a careful description, accompanied by geological maps where these are available, of the chief sources of the commercial ores, each producing country being considered separately. This account is very complete and includes, for the radioactive metals, a consideration of the natural waters containing radioactive material, particularly in Germany. Each section concludes with a short account of the metallurgy and uses of the metal under consideration, and a survey of the present market position in relation to world production, accumulated stocks, and price. The book is well printed, but no detailed index is provided. STEPHEN L. ROBERTON.

PINDER, S. "*Panel Beating and Sheet Metal Work.*" A Practical Guide for Students in Technical and Trade Schools, and for Apprentices and Workers in Motor and Aero Sheet Metal Work. 8vo, pp. vii + 88. Illustrated. London, 1937: Sir Isaac Pitman and Sons, Ltd. (Price 4s.)

The subject matter in this booklet is divided into three parts dealing with flat work, panel beating, and oxy-acetylene welding; each part is then further subdivided. This arrangement is much to be commended, and contributes largely to the comfort of the student or the reader. Of the individual chapters, some slight criticism must be made of Chapter I., which treats of the properties of metals and briefly outlines their metallurgy; statements occur which, if not entirely erroneous, are at least decidedly loose, as, for example, that which says that manganese "is used for making self-hardening steel." Similar criticism might be levelled against the claim that "terne plates or lead-coated steel have a deposit of lead applied in a similar way and are not very much used nowadays." The chapters dealing with practical sheet metal work are excellent, and sketches and diagrams have been chosen with great care. In the last part some mention of electric welding would not have come amiss.

SVETCHNIKOFF, V. N., and R. F. STARODUBOFF. "*Ingot Moulds. Composition, Structure, Properties and Strength.*" 8vo, pp. 188. Illustrated. Dnepropetrovsk. U.S.S.R., 1933. (In Russian.)

The first part of Professor Svetchnikoff's book is devoted to an investigation of the life of ingot moulds as dependent on the composition and structure of the iron from which they are made. This is followed by a critical examination of literature on the subject and a review of the results of the author's own experimental work. Some study of the methods of choosing samples for investigating structure is included. In the second part of the book the author covers the various types of breakdown to which the walls of the ingot mould are subject in practice; the influence of structure and composition in this regard are dealt with, and the life of the mould is discussed in relation to

experimental results obtained on the growth of cast iron with repeated heating; moulds of pearlitic iron are claimed to yield the longest life. A lengthy bibliography adds considerably to the value of the work.

TOWNSEND, W. S. B. "*The Development of Sheet Metal Detail Fittings for Bench Fitters and Toolmakers, &c.*" 8vo, pp. v + 42. Illustrated. London, 1937: Sir Isaac Pitman and Sons, Ltd. (Price 2s. 6d.)

The author is to be commended for his aim in compiling this little book; he is "not unhopeful that it will supply a long-felt want, and be the means of eliminating wasteful and unsatisfactory 'rule of thumb' methods which are now in widespread use." After a brief incursion into the geometry of the circle, the practical implications of such geometry are at once driven home by their application to the development of the simpler sheet metal fittings. Progress continues with forms of increasing complexity, until in Chapter II. simple trigonometry is touched on, its terminology shortly explained, and its application to the work in hand demonstrated. An excellent booklet, clearly printed, aptly illustrated and pleasantly free from all extraneous matter.

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IRON AND STEEL INSTITUTE. Special Report No. 19. "*Foamed Blast-Furnace Slag.*" By T. W. Parker. Blast-Furnace Committee Report No. 19. Being a Report of the Slag Tests Panel to the Blast-Furnace Committee of the Iron and Steel Industrial Research Council. 8vo, pp. iv + 32. London, 1937: The Institute. (Price 5s.)

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THORPE, JOCELYN FIELD, and M. A. WHITELEY. "*Thorpe's Dictionary of Applied Chemistry. Fourth edition. Vol I.: A–Bi.*" 8vo, pp. xxvii + 703. London, New York and Toronto, 1937: Longmans, Green and Co., Ltd. (Price 63s.)

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REFRACTORY MATERIALS

(Continued from p. 165 A)

The Properties of Magnesite and Chrome-Magnesite Bricks. J. H. Chesters and L. Lee. (Transactions of the Ceramic Society, 1937, vol. 36, July, pp. 294–310). The trend towards the all-basic furnace directs attention to the properties necessary in open-hearth roof bricks, where few magnesite or chrome-magnesite bricks have given good results. High spalling resistance and refractoriness-under-load, and the absence of after-shrinkage are essential. Two bricks were found to fulfil these conditions, both being essentially composed of chrome-magnesite in the ratio of 75 : 25 (with the latter in the fine section) and a forsterite bond.

Refractory Concretes for Coke Ovens and Furnaces. W. M. McGrue. (Blast Furnace and Steel Plant, 1937, vol. 25, June, pp. 624–627). The author traces the development of high-alumina hydraulic binders for refractory aggregates, and describes the construction of coke-ovens fitted with door-liners of this concrete. The composition of the refractories is given, together with details of their manipulation.

Hearth Refractories for Steel Making. W. J. MacCaughey and H. C. Lee. (Metals and Alloys, 1937, vol. 8, June, pp. 153–157). The author describes briefly the significance of the chemistry of the acid and basic processes in relation to the nature of the hearth refractory employed, and then proceeds to a more detailed account of the requirements of a hearth refractory for the basic process. Dolomite and periclase are dealt with, together with the importance of interstitial bond and the action of calcium ferrite in this connection. A calcium-ferrite-bonded refractory is described and the difficulties encountered in its development are discussed.

Insulating Refractories. G. A. Bole. (American Foundrymen's Association, 1937, Preprint No. 37–20). A review is given of the manufacturing methods, properties, testing, specification, and applications of insulating refractories. Means of obtaining a cellular structure are described, and manufacturing difficulties discussed. The use of large shapes is advocated. The advantages to be gained from the use of refractories of this type are examined under the headings of thermal conductivity and furnace construction. Some precautions to be taken in the use of these refractories are considered.

The Conservation of Heat by Insulation. W. Goldsbrough and S. G. Throssell. (British Steelmaker, 1937, vol. 3, July, pp. 295–298). A brief mathematical treatment of the problem of heat losses in furnaces followed by an account of practical methods of heat insulation.

FUEL

(Continued from pp. 166 A–168 A)

The Significance of Ash Softening Temperature and Ash Composition in the Utilisation of Coal. A. W. Gauger. (American Society for Testing Materials, 1937, Preprint No. 78). The paucity of experimental data on the correlation of ash softening temperature measurements with clinker formation is pointed out. There is no general correlation between ash softening temperature and clinker formation for the classes of utilisation discussed, namely, underfeed stoker, pulverised fuel, domestic, and water-gas generation. Little is known about the effects of ash composition, although the presence of iron oxide in the ash in excess of 20% is held by some to be detrimental.

Recent Developments of Energy Resources in Germany and the United States. T. W. Wedding. (Glückauf, 1937, vol. 73, Aug. 21, pp. 773–783). The author examines and compares the energy resources, including solid and liquid fuels, natural gas and water power, in Germany and the United States, and traces the course of their development during recent years.

Chequer-Work Bricks in Open-Hearth Furnaces. A. B. Searle. (Iron and Steel Industry, 1937, vol. 10, July, p. 522). The author discusses the defects and difficulties experienced in operating regenerators and hot stoves and shows that these may be attributed to faulty design of the regenerator and to the effects of flue dust. The durability of regenerator bricks and the influence of gas velocity on this are noted.

Fuel Economy in Melting and Reheating Furnaces. R. J. Sarjant. (Journal of the Institute of Fuel, 1937, vol. 10, Aug., pp. 355–377). The author discusses the salient factors governing the performance of melting and reheating furnaces under the following heads: Bearing of the fuel used on economy; fundamental relationships between fuel consumption and various known sets of conditions; structural details and operating conditions of reheating furnaces; analysis of furnace performance; operation control in theory and practice; regenerator temperatures; carbon dioxide recorders and the effects of excess air; heat flow into the charge, from th practical and mathematical standpoints; heat storage and insulation and the significance of uninsulated walls; and regeneration.

Interpretation of Laboratory Coal Tests.—Proximate Analysis and Calorific Value. G. B. Gould. (American Society for Testing Materials, 1937, Preprint No. 79). The behaviour of coal is dependent on the combination of all its properties, and upon the conditions of use under a wide variety of conditions. The calorific value is the only laboratory test which provides a positive measure

of its value as a fuel. Proximate analyses, moisture, ash, volatile matter and fixed carbon relate to the chemical or physical properties which affect its performance.

The Significance to the Consumer of Sulphur in Coal. H. Kreisinger. (American Society for Testing Materials, 1937, Preprint No. 80). The author discusses the significance of sulphur in coal for steam-raising purposes from the viewpoint of the user.

Significance of Friability and Size Stability. Tests on Coal. R. E. Gilmore and J. H. H. Nicolls. (American Society for Testing Materials, 1937, Preprint No. 82). The authors examine the significance of the tentatively standardised tumbler and drop-shatter tests for coal. Tabulated data are presented.

Practical Tendencies in the Preparation of Lignite in Belgium and Holland. C. Berthelot. (Génie Civil, 1937, vol. 111, Aug. 28, pp. 181–186). A description is given of plant installed for cleaning lignite at Les Charbonnages de Limbourg-Meuse.

Pulverised Performance as Affected by Grindability and Other Factors. M. Frisch and A. C. Foster. (American Society for Testing Materials, 1937, Preprint No. 77). The authors present tabular and graphical data on the results of investigations on the pulverising characteristics of various coals, and conclude that no two methods assign the same relative pulverising characteristics to any given coal, that the ratings assigned by two tentative methods noted differ, but may be correlated as the results may be accurately checked and repeated, that relative ratings from standardised tests on commercial pulverisers give closer ranking than standard laboratory tests, and that pulverisers of the same type, but of different sizes, do not rank coals alike. Laboratory grindability ratings may be used to predict the performance of a pulveriser on a coal of known grindability under special conditions, and a large number of coals tested by the method of Hardgrove as modified by Frisch and Holder (the F.W. method) can now be correlated with grindabilities obtained by other methods.

Installation for the Dry Quenching of Burning Coke. O. Huber. (Chaleur et Industrie, 1937, vol. 18, June, pp. 259–264). The author describes in some detail the dry quenching plant for coke at the Dagenham works of the Ford Motor Co.

Laboratory Tests Relating to Caking, Plastic, Gas-, and Coke-Making Properties of Bituminous Coals. O. O. Malleis. (American Society for Testing Materials, 1937, Preprint No. 81). The author indicates the practical significance of tests to determine the caking, plastic, gas-, and coke-making properties of bituminous coals.

Characteristics of Coal Plasticity. R. G. Atkinson, R. E. Brewer, and J. D. Davis. (Industrial and Engineering Chemistry, 1937, vol. 29, July, pp. 840–844). The authors describe the results of experimental work upon the mechanism of coal plasticity during coking.

The Fundamental Principles of Coke-Oven Development. T. B. Smith. (Proceedings of the Cleveland Institution of Engineers, 1936–1937, No. 4, pp. 101–145). The author presents a general review of developments in the coking and by-product industries. Coal blending, ovens and oven design, refractories, heating methods, coke-screening, dry-cooling, and gas recovery are among the features detailed.

The Uniform Heating of Coke Ovens. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, June, pp. 83–85). The problem of uniform horizontal heating in the coke-oven is discussed, and the question of end heating, particularly with reference to heat loss is dealt with. Data are presented in tabular form.

Low-Temperature Carbonisation of Bituminous Coal. D. Brownlie. (Industrial and Engineering Chemistry, 1937, vol. 29, July, pp. 734–741). The author gives details concerning the development and present position of low-temperature carbonisation practice for bituminous coals in England and Germany. Fifteen processes are enumerated and critically examined.

The Carbonisation of Coal with Electricity. H. Stevens. (Fuel Engineers of Appalachian Coals, Fourteenth Meeting, May 11, 1936). The author explains the principles of electrical carbonisation, quoting Walker of the Detroit Edison Co. The technical and economic aspects examined by the latter are discussed by the author, who reproduces Walker's tabulated results of investigations on the process.

Foundry and Laboratory Characteristics of Cupola Cokes. H. O'Neill and J. G. Pearce. (Institute of British Foundrymen, June, 1937: Foundry Trade Journal, 1937, vol. 57, July 15, pp. 46–50; July 22, pp. 66–72; July 29, pp. 87–88). To determine which of the existing laboratory tests give useful indication of the foundry behaviour of cupola cokes, and to ascertain the qualities of these cokes, the following tests were carried out: Foundry trials, using a cupola with an output of about 60 tons per day of uniform metal; determinations of the carbon and sulphur pick-up, using the British Cast Iron Research Association experimental balanced-blast unit; laboratory tests of a physical, chemical and structural nature. In the discussion, J. K. Smithson gave, in tabular form, figures for three makes of average quality Durham patent blast-furnace coke; from these it is deduced that the value of the high-ash small material in the cupola is very limited.

Improvement in the Control of Gas Producers. G. Neumann. (Stahl und Eisen, 1937, vol. 57, Aug. 12, p. 904). The author describes a device whereby, instead of two measurements having to be taken and their difference calculated for estimating the pressure drop in producers, this difference is read off directly. The importance of checking the value of the pressure drop is discussed, and precautions to be taken in measurements of blast pressure and other factors are noted.

PRODUCTION OF IRON

(Continued from pp. 169 A–173 A)

Developments in Production Metallurgy of Iron and Steel. G. B. Waterhouse. (American Iron and Steel Institute, May 27, 1937). The author reviews briefly some recent developments in blast-furnace design and operation, open-hearth practice and rolling-mill practice.

Million-Dollar Blast-Furnace. (Iron and Steel Engineer, 1937, vol. 14, July, p. 56). A description is given of the new blast-furnace in course of construction for Hamilton Coke and Iron Co., Hamilton, Ohio.

All-Welded Blast-Furnace Stove Operated at English Plant. H. M. Henderson. (Steel, 1937, vol. 101, July 12, pp. 65–67). An account is given of the all-welded blast-furnace stove in operation at the Appleby works of the Appleby-Frodingham Steel Co., Ltd., Scunthorpe.

The English Iron and Steel Industry Now and in the Future. J. W. Reichert. (Stahl und Eisen, 1937, vol. 57, Sept. 2, pp. 969–979). The author reviews in detail the economics and organisation of the English iron and steel industry at the present time, and discusses fully the future developments and progress which present trends indicate as possible or desirable.

Technological Advances in Steel Products. C. M. White. (American Iron and Steel Institute, May 27, 1937). The author reviews the statistical position of raw materials in the United States, surveys the recent developments in equipment as illustrated by individual furnaces or mills representative of the latest practice, discusses production methods and standards, examines operation costs, and comments on marketing procedure and future developments.

The Foundations of the Turkish Iron Industry. B. Granigg. (Stahl und Eisen, 1937, vol. 57, July 29, pp. 833–837). The author reviews the development of the Turkish iron industry, its geographical situation, the coal and iron resources of the country, and the nature and sources of refractories and alloying elements. Data in connection with iron ores are tabulated, and their chemical and geological characteristics are indicated.

The Hundredth Anniversary of the Borsig Works of the Rheinmetall-Borsig A.-G. (Stahl und Eisen, 1937, vol. 57, July 22, pp. 820–821). A brief summary is given of the volume issued by the Rheinmetall-Borsig A.-G. to commemorate their hundredth anniversary, and entitled " Deutscher Maschinenbau, 1837–1937, im Spiegel des Werkes Borsig."

FOUNDRY PRACTICE

(Continued from pp. 174 A–176 A)

The Function of Tuyeres in Cupola Operation. H. V. Crawford. (Iron Age, 1937, vol. 140, July 29, pp. 29–32, 45). After noting the general functions of the tuyeres in the cupola, the author discusses various modifications in tuyere design, and describes the combustion processes occurring in the cupola and the relation of these processes to tuyere location. Atmosphere control and the attainment of even melting are dealt with, together with the " softness " of the blast and the reduction of sulphur pick-up.

The Commercial Production of Refined Pig Irons for High-Duty Castings. G. T. Lunt. (International Foundry Congress, Paris, 1937: Foundry Trade Journal, 1937, vol. 57, Aug. 12, pp. 117–118). The author describes briefly the evolution and development of refining processes, enumerates and characterises types of refined irons, and discusses variations in production methods. Rotary-furnace melting and duplex processes are treated in some detail, and the applications of refined irons are noted.

Special Pig Irons in the Foundry. E. A. Jones. (Foundry, 1937, vol. 65, June, pp. 35, 86). The author describes the use of special pig iron in charges designed for the production of high-duty irons, or for the purpose of controlling the carbon content.

Developments in the Production of Malleable Castings.—VIII. Annealing or Malleableising—Some Considerations. H. H. Shepherd. (Iron and Steel Industry, 1937, vol. 10, July, pp. 515–519). The author discusses packing media, " peeling," the annealing cycle, annealing pots, the annealing of blackheart malleable iron, and the relationship between the temperature and graphitisation. (*See* Journ. I. and S.I., 1936, No. II., p. 248 A).

Malleable Iron-Melting Practice–Retrospective and Prospective. H. H. Shepherd. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Aug. 12, pp. 121–124; Aug. 19, pp. 143–147; Aug. 26, pp. 163–166). After a preliminary review of the development of the malleable cast iron industry and production statistics, the author examines the sources and control of raw materials (scrap and pig), and discusses various melting methods, including the duplex and triplex processes and electric furnace melting. Superheating and pouring temperatures are also dealt with.

Selection of Cycle and Furnace for Annealing Malleable Iron. A. F. Landa. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 41–60). The author investigates the annealing cycles and equipment used for the annealing of malleable cast iron. Each cycle is illustrated schematically and

divided into periods. The choice of a suitable cycle is discussed and the adaptability of various heating furnaces for this purpose is examined. It is concluded that an optimum annealing rate exists for each iron according to the equipment available. Furnaces should be designed to suit the cycle adopted and the casting to be treated, while the cycle can be reduced by lowering "non-productive" times. A tunnel kiln specially designed to reduce annealing times is described.

Summary of Second Report of the Steel Casting Research Committee Special Report No. 15, 1936, The British Iron and Steel Institute. C. W. Briggs. (American Foundrymen's Association, 1937, Preprint No. 37–16).

American Sand Testing Technique. E. Woodliff. (New England Regional Foundry Conference: Foundry Trade Journal, 1937, vol. 57, July 29, pp. 79–80, 85). The author describes the purpose of sand testing, and the tests, testing apparatus, and manipulative technique required for efficient foundry control.

A New Method of Making Pattern Plates. G. Delcroisette. (Revue de Fonderie Moderne: Foundry Trade Journal, 1937, vol. 57, Aug. 19, pp. 141–142). The author describes a method of making pattern plates suitable for adoption in smaller foundries possessing no moulding machines, and which is claimed to effect a reduction in pattern-plate costs. Full working details are given.

Gear Castings with Special Reference to Cast Iron. O. Smalley. (American Gear Manufacturers' Association: Foundry Trade Journal, 1937, vol. 57, July 22, pp. 62–65; July 29, pp. 81–85). The author discusses the requirements of material for gears and the evolution of the modern cast irons, and subsequently considers in detail the fatigue properties and damping capacity of cast irons in relation to the same properties in steels. Meehanite cast iron is particularly referred to. In regard to this last type of iron, the influence of mass and applications based on its special properties are dealt with in detail, data being presented in graphical and tabular form.

Studies on the Solidification and Contraction in Steel Castings.—V. Contraction Stresses. C. W. Briggs. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 61–81). The author discusses the fundamental principles underlying contraction in steel castings. Plastic and elastic deformation at elevated temperatures, stress centralisation, the magnitude of contraction stresses at hot-tearing and room temperatures, and the effect of solidification on contraction stresses, are considered in detail. (*See* Journ. I. and S.I., 1936, No. II., p. 152 A).

PRODUCTION OF STEEL

(Continued from pp. 177 A–181 A)

New 300-Ton Open-Hearth Furnace Installation at Appleby-Frodingham. (Iron and Coal Trades Review, 1937, vol. 135, July 30, pp. 182–183). A comprehensive account is given of the construction of the new 300-ton tilting open-hearth furnace at the works of the Appleby-Frodingham Steel Co., Ltd. The furnace is arranged to roll on 12 articulated rollers and has a bath 45 ft. long by 15 ft. wide.

U.S. Steel Breaks Ground for Irvin Works. (Blast Furnace and Steel Plant, 1937, vol. 25, June, pp. 628–629). An account is given of the layout and plant at the Irvin works of the Carnegie-Illinois Steel Corporation.

Variation in the Turning Moment of a Converter Consequent upon Alteration in its Condition, and Possibilities of Controlling it. H. König and H. Meinert. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, July, pp. 1–10). Methods of measuring the turning moment of a converter are described, and the results obtained are compared with those deduced mathematically. Alterations in the turning moment result from loss in weight of the bottom and refractory lining; if accretions at the mouth and wear of the pouring channel are taken into account, König's method for determining the turning moment gives reliable results. Various methods of maintaining a constant turning moment are described and illustrated.

Cooling with Ore in the Basic Bessemer Steel Plant. E. Spetzler. (Stahl und Eisen, 1937, vol. 57, Aug. 5, pp. 865–870; Aug. 12, pp. 899–900). Pig iron and lime can, in general, replace scrap to only a limited extent as a means of absorbing excess heat in the basic converter. Under suitable conditions, however, a rich ore low in phosphorus can be economically employed as a substitute for scrap, the iron being taken up into the bath. The results of experimental work are described in detail, and data are presented in tabular form.

2-Ton Electric Charger, Three-Cycle Type, by Dango and Dienenthal. (Génie Civil, 1937, vol. 111, Aug. 14, p. 105). A description is given of an electric charging equipment suitable for open-hearth furnaces, produced by Dango and Dienenthal. Details of design and operating data are given.

REHEATING FURNACES

(Continued from p. 135 A)

Soaking-Pit Furnace. New Design and Operation. P. M. Offil. (Iron and Steel Engineer, 1937, vol. 14, June, pp. 17–21). A description of, and data relating to, a new form of soaking-pit furnace, in which the flow of heated combustion gases is directed along the long axes of all ingots simultaneously, and equidistant from them, are given. In this furnace each pit and recuperator has an independent fuel and air supply system.

Regenerative-Type Soaking Pit for Use with Lean Fuels. (Iron and Steel Engineer, 1937, vol. 14, July, pp. 53–54). A description is given of the regenerative soaking pit designed by the Rust Furnace Co., for use with unmixed blast-furnace gas or a mixture of this with coke-oven gas. The essential feature of the design consists of extra large regenerating chambers for preheating the air to a very high temperature. Automatic temperature control is provided.

Gas-Fired Slab Heaters. J. B. Nealey. (Iron Age, 1937, vol. 140, July 15, pp. 39–40). The author describes the continuous slab-heating furnaces installed at the McDonald works of the Carnegie-Illinois Steel Corp. Heating is effected by 24 gas burners arranged in three groups, and zone control is obtained by the use of an independently fired heating chamber and soaking chamber.

FORGING, STAMPING AND DRAWING

(Continued from p. 182 A)

The Mechanism of Forging. H. Hayes. (Iron and Steel Industry, 1937, vol. 10, July, pp. 549–551). The author describes experiments to determine the flow processes occurring in steel during forging operations. The mechanism of flow is discussed.

Drop Forgers Adopt Standard Tolerances. (Iron Age, 1937, vol. 140, July 15, pp. 47, 120). (*See* p. 184 A).

Axe-Making Retains Craftsmanship. J. B. Nealey. (Iron Age, 1937, vol. 140, July 29, pp. 40–42). A description is given of the manufacture of hand-forged axes. Gas forging furnaces, and gas-heated lead and salt pots for hardening and tempering are employed, the former process having been previously conducted in electrically heated furnaces. Town gas is used in all cases.

A Modern Tin-Box Works. Palmers Green Plant of Metal Box Co., Ltd. (Sheet Metal Industries, 1937, vol. 11, July, pp. 631–632). An account is given of the layout and production of a modern can-making works. Details are given of blanking, forming and soldering operations, and the types of plant employed are specified and described.

The Metallurgy of Steel Wire. B. L. McCarthy. (Wire Association, May 21, 1937 : Wire and Wire Products, 1937, vol. 12, July, pp. 343–347). The importance of structural and chemical control of raw material for wire manufacture is indicated by consideration of the composition and metallography of typical steels employed in the wire industry.

Lubrication and its Part in Efficient Production. (Wire Industry, 1937, vol. 4, July, p. 328). The application of lubricants in wire-drawing, the results of inefficient lubrication, and the choice of lubricants for various given conditions are discussed. Some proprietary compounds are referred to.

ROLLING-MILL PRACTICE

(Continued from pp. 183 A–184 A)

Hot-Rolling Tests on Unalloyed and High-Alloy Steels under Different Conditions of Rolling. G. Weddige. (Stahl und Eisen, 1937, vol. 57, Aug. 19, pp. 913–920). After a brief review of earlier work, the author describes the apparatus employed in his own investigations on the rolling of low-carbon, high-carbon, low-carbon/high-silicon, high-chromium, nickel-chromium and nickel-chromium-tungsten or aluminium steels. Graphical data are presented showing the area of rolled surface and the roll pressure in relation to the percentage reduction at various temperatures, the mean resistance to deformation in relation to the percentage reduction, the turning moment in relation to the reduction, and the forward-slip in relation to the rolling temperature. In the discussion which follows, W. Lueg presents further data on the resistance to deformation of alloy and non-alloy steels at commercial rolling temperatures.

New Continuous Rod Mills. American Steel and Wire Co., Joliet, Illinois. (Iron and Steel Engineer, 1937, vol. 14, July, pp. 50–52). (*See* p. 186 A).

Mechanical Developments of Modern Cold Rolled Strip Mills. J. L. Young. (Iron and Steel Engineer, 1937, vol. 14, July, pp. 19–26). The author describes in some detail typical modern cold-strip mills installed at various representative works in America.

Electrical Operation of Cold Strip Mills. A. F. Kenyon. (Iron and Steel Engineer, 1937, vol. 14, July, pp. 27–38). After a brief historical introduction, the author passes on to a consideration of the problems encountered in operating cold-strip mills electrically, and discusses equipment installed to drive particular mills. Tabulated operating data for typical plants and wiring diagrams for the mills and auxiliary plant are given.

Conveying Systems for Severe Duty Service. F. Juraschek. (Iron Age, 1937, vol. 140, July 22, pp. 45–50, 123). The author describes the practical requirements of conveyor systems for sheet and coil in the mill, and for foundry service.

Side-Tilter for Strip Steel Conveyors has Longitudinal Leveling Feature. C. Plock. (Iron Age, 1937, vol. 140, July 15, p. 41). A short account is presented of the essential features of the Logan levelling-type side-tilter for strip-steel coils. With this equipment, discharge is effected without lifting.

Pressures and Roll-Flattening in Cold Rolling. W. Trinks. (Blast Furnace and Steel Plant, 1937, vol. 25, June, pp. 617–618, 623). A mathematical treatment of roll pressure and flattening in cold-rolling is presented.

PYROMETRY

Reliability of Common Types of Thermocouples. D. Quiggle, C. O. Tongberg, and M. R. Fenske. (Industrial and Engineering Chemistry, 1937, vol. 29, July, pp. 827–830). The results of tests carried and to determine the reliability of certain types of thermocouple indicate that the heat treatment of copper-copel, chromel-alumel, and copper-constantan couples causes a variation to occur between readings obtained before and after treatment when this takes place above 200° C., the variation increasing as the treatment temperature increases. Between treatment temperatures of 200° C. and 300–350° C., the first and last types show a positive error, while above 350° C., they show a negative error, and it is suggested that the range of greatest reliability is from 0° C. to 200° C.

The Fitterer Pyrometer for Measuring Liquid Steel Temperatures. (Iron Age, 1937, vol. 140, July 22, pp. 38–40). Brief working details are given of the portable carbon/silicon-carbide thermo-electric pyrometer manufactured by the Fitterer Pyrometer Co. A potentiometer designed for use with the couple is also described.

Temperature Measurements in the Steel Bath of the Basic Open-Hearth Furnace. G. Leiber. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 63–66). Based on earlier experiences with tungsten-molybdenum couples, the newly designed apparatus constructed by the author enables repeated measurements to be made with great accuracy and safety. Simultaneous optical measurements enabled the emission coefficient of liquid steel to be determined; its value is shown to depend on the appearance of the steel surface; a mean value of $\varepsilon = 0{\cdot}445$ was obtained for darker surfaces. Measurements of the temperature of the slag surface indicate that the emission of the hearth space lies only a little under 1·0.

Methods of Measuring Gas Temperatures and their Errors. R. Hase. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, May 15, pp. 571–575). Methods for measuring the temperature of gases can be divided into two groups: Those employing apparatus sensitive to heat, and those in which some property of the gas which varies markedly with the temperature is measured. With instruments of the first group, exact results are obtained only when the sensitive member is in thermal equilibrium with the gas at the moment of making the measurement; the choice and use of this class of appliance should be guided by recognition of this fact. Regarding the indirect measurement group, use has been made of observations of the density of the gas, and more recently attempts have been made to use its spectrum as a measure of its temperature.

HEAT TREATMENT

(Continued from pp. 185 A–187 A)

Hardening Machines. E. Zorn. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Aug. 28, pp. 1020–1021). A description is given of flame-hardening machines suitable for gears and shafts.

Nitrogen Hardening of Cast Iron. (Iron Age, 1937, vol. 140, July 15, pp. 80–83). (*See* p. 187 A).

A Continuous Heat Treating Furnace in a Steel Foundry. J. H. Hall. (Iron Age, 1937, vol. 140, July 22, pp. 41–44). The author describes in detail the construction and operation of a continuous-type furnace for the heat treatment of manganese-steel castings. Firing is by means of light fuel oil.

Enlarged Electric Heat-Treating Facilities Bring Advanced Practice. (Steel, 1937, vol. 101, July 26, pp. 62–64). An account is presented of the layout of the heat treatment shop at the Bethlehem works of the Bethlehem Steel Co. Carbon and alloy steel bars are dealt with, and all furnaces are electrically operated; controlled atmospheres are provided where necessary, the requisite gas being made in a special producer.

Heat Treatment of Tool Steels. (Iron and Steel Industry, 1937, vol. 10, July, pp. 551–552). The heat treatment technique for carbon and alloy tool steels is described, requisite quenching and tempering temperatures being noted; some discussion on the theoretical aspects is included.

Controlled Atmosphere Furnaces for Annealing Tubing. (Industrial Heating, 1937, vol. 4, July, pp. 541–542, 548). A description is given of the controlled-atmosphere furnace for the normalising of resistance-welded steel tubing installed in the Cleveland plant of Steel and Tubes, Inc. The furnace is built in two sections, the furnace proper and the cooling chamber. Working in conjunction with this furnace is a gas-fired blueing furnace operating at 650° F.

A Recent Installation of Vertical Forced Air Circulation Furnaces. (Wild Barfield Heat-Treatment Journal, 1937, vol. 2, June, pp. 67–70). A detailed account is given of a recently completed installation of two vertical forced-air-circulation electric furnaces. The description includes the furnace construction and specifications of the switch-gear and electric hoist.

The Heat Treatment of Special Steels. R. Saxton. (Wire Industry, 1937, vol. 4, June, pp. 295–297). The essential details of, and peculiarities in, the heat treatment of steels containing chromium, nickel, tungsten, manganese, and chromium-aluminium are described. Certain special properties of the steels are noted.

Electrical Heating Furnaces With Protective Atmosphere in the United States. J. Eberwein. (Stahl und Eisen, 1937, vol. 57, Aug. 26, pp. 945–949). Typical American equipment for bright-annealing is described together with plants for producing the requisite atmosphere which are sufficiently economical to enable conveyor-type furnaces to be operated with controlled atmosphere; such plants employ natural gas, coke-oven gas or coal gas as raw material. The economic value of the procedure is reviewed in a survey of comparative costs.

Mass Production Hardening at Chevrolet. J. B. Nealey. (Heat Treating and Forging, 1937, vol. 23, June, pp. 295–297). A detailed description is presented of the heat treatment department of the Chevrolet Motor Co., Bay City, Mich. Gas-fired furnaces, mostly mechanised and automatically controlled, are employed.

Studies on the Cooling Action of Quenching Liquids by the Schlieren Method. G. Shinoda and K. Tatibana. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, May, pp. 151–152). The mechanics of heat interchange between a metal and a quenching medium were studied by means of a duralumin rod quenched from 500° C. in various liquids. With water and 10% aqueous sodium chloride, heat flow occurs initially at right angles to the specimen, convection occurring later with a maximum velocity near the surface of the metal. Viscous media, such as glycerine and castor oil, exhibit limited convection in an annular zone around the specimen, the diameter of the zone and the duration of its existence depending on the coefficient of viscosity, the thermal expansion and the heat conductivity of the quenching liquid. Hence the quenching process may be divided into two stages: The transient stage when, in the case of water and salt solutions, most heat is abstracted, and the stationary stage when, in the case of viscous media, the major cooling action occurs, although rather slowly. (In Japanese).

Tempering Springs and Similar Small Components. (Wire Industry, 1937, vol. 4, June, pp. 291–292). The structure of the forced-air-circulation electric furnace is briefly described, and its advantages and applications are noted. Other furnaces for hardening and tempering strip and for bright-annealing strip and wire are also dealt with.

Road-Vehicle Spring-Making Plant of Samuel Fox & Co., Ltd. (Iron and Coal Trades Review, 1937, vol. 135, Aug. 6, p. 214). A brief account is presented of the production cycle in the manufacture of road-springs at Samuel Fox and Co.'s works. Continuous-type furnaces are employed for heat treatment.

WELDING AND CUTTING

(Continued from pp. 188 A–190 A)

Analysis of Laws, Decrees, Orders, Circulars and Prescriptions Relating to Equipment and Raw Materials for, and the Execution of Work by, Oxy-Acetylene and Arc Welding. (Revue de la Soudure Autogène, 1937, vol. 29, Aug., pp. 169–196). A digest is presented of all the more important sections of laws and decrees relating to arc and gas-welding in France.

Oxy-Acetylene Welded Pipe Joints. Scope, Utility and Economics. T. W. Greene. (Metal Progress, 1937, vol. 32, July, pp. 36–41). The author outlines the field of utility for welded pipe joints, and notes briefly minor points in welding technique, referring particularly to the modified layer-method. Economy in layout and erection are dealt with.

Study and Control of Oxy-Acetylene Welding in Aircraft Construction. E. Zavattiero. (Metallurgia Italiana, 1937, vol. 29, July, pp. 337–349). The author discusses briefly the applications of oxy-acetylene welding in aircraft construction, and notes the compositions of steels suitable for welding and for welding rods. Testing methods are described, and the application of these to welded sheet is discussed. The influence of heat treatment is dealt with, and the results of X-ray and magnetic tests are presented.

Methods Used in Making Invisible Spot Welds. M. W. Roth. (Steel, 1937, vol. 101, July 12, pp. 44–48). The author describes the technique and plant required for the so-called "invisible" spot-welding process, and reviews briefly the uses of the method, the nature of the weld, and the types of alloy suitable for electrodes.

Interrupted Spot Welding Uses Electron Tube Control. R. S. Pelton. (Metal Progress, 1937, vol. 32, July, pp. 59–62). The application of thyratron tube control for interrupted spot welders is described and the technique of the process discussed.

Arc-Welding Continually Advances in Pipe Line Construction. A. F. Davis. (Metal Progress, 1937, vol. 32, July, pp. 46–49). The author describes the welding technique required for pipe-line work for water, steam, oil, and gas, more especially in connection with "field work."

Sound Welds in Very Thick Plate a Routine Matter. H. S. Blumberg. (Metal Progress, 1937, vol. 32, July, p. 66). A welded joint in carbon steel plate 4·5 in. thick is described.

The Influences of the Electric Arc on the Properties of Weld Metal. E. F. Newell. (Electric Welding, 1937, vol. 6, Apr., pp. 102–104; June, pp. 161–164). The author presents the results of an investigation into the effect of the reactions that occur in the arc on the properties of the weld metal. He discusses the

deposition of metal in the electric arc, and describes the effect of atmospheric gases on the weld, the reactions occurring between elements in the electrode, and the effect of current conditions on the weld metal.

Peening and Its Effects on Arc Welds. E. M. McCutcheon and D. M. Kingsley. (Welding Journal, 1937, vol. 16, July, Supplement, pp. 22–28). Cold peening is shown to reduce shrinkage strains in welds more effectively than hot peening, but to yield poorer bend ductility. In single-bead welds, peening is injurious. On rigidly constrained welds cold peening only is effective in reducing shrinkage strains. To prevent the cracking of multiple-bead welds, each bead may be hot peened.

Residual Strains and Stresses in Arc-Welded Plates. M. E. Lance Martin. (Transactions of the North East Coast Institution of Engineers and Shipbuilders, 1936–37, vol. 53, pp. 255–280). The basic principles of the fabrication of structures by fusion welding are discussed and the investigation by laboratory methods of residual stresses in welded plates is described. The preparation of specimens and the measuring instruments employed are dealt with, and data obtained are collated and analysed.

Welding and Cutting for Colliery Repairs. (Colliery Engineering, 1937, vol. 14, July, pp. 233–234). The use of welded or built-up parts assists in reducing maintenance and replacement costs in colliery plant. The jointing of pipes, fabricating components of sheet metal, the application of hard-facings, engine and pump repairs, and the manipulation of wire ropes and track rods are dealt with.

Flame Cutting in the Foundry. Removal of Chromium-Nickel Steel Risers. C. H. S. Tupholme. (Welding Industry, 1937, vol. 5, June, pp. 160–161). Difficulties associated with the removal of big risers in chromium-nickel steel by grinding or flogging have led to the development of a satisfactory flame-cutting technique. Details of the equipment required and of the operating procedure are given.

Smooth and Rapid Flame Cutting of Plate 8 in. thick. H. Diergarten. (Metal Progress, 1937, vol. 32, July, pp. 68, 74). The use of the improved cutting nozzle of Zobel is described and the theory of its action examined.

CLEANING AND PICKLING OF METALS

(Continued from p. 144 A)

Rotary Mast-Type Machine Pickles Hot-Strip Steel at Low Cost. (Steel, 1937, vol. 101, July 19, pp. 68–70). The rotary pickling plant installed at the United Engineering and Foundry Co.'s works at Pittsburgh is described. It is capable of handling two 42-in. coils on each of four mandrels, and has an output of 60 tons per hr. for 13-gauge sheet.

The Working-Up of Spent Pickling Solutions. (Stahl und Eisen, 1937, vol. 57, July 8, pp. 757–764; July 15, pp. 789–793; July 22, pp. 813–817; July 29, 838–840). A series of articles dealing with the recovery of spent pickling solutions, and comprising the following subjects:

(i) A general review of recovery methods, by F. Heinrich.

(ii) The economic significance of the water supply for pickling, by M. Prüsz.

(iii) Individual methods: (*a*) The Agde process, by G. Agde; (*b*) The Sulfrian method, by A. Sulfrian; (*c*) Recovery plant for waste water from pickling plant, with continuous pickling and constant acid concentration, by F. Sierp and F. Fräusemeier; (*d*) Recovery methods involving recrystallisation, by J. Draaff; (*e*) The Feracid-Clear-Pickle method, by W. Heimberger.

Hydrogen Permeability of Steel During Electrolytic Pickling. W. Baukloh and W. Retzlaff. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 97–99). It is shown by investigation of 0·1% carbon steel sheet, 0·2 mm. in thickness and with a structure coarsened by annealing in hydrogen at 900–1000° C. and by recrystallisation, that grain size has practically no influence on its permeability to hydrogen during electrolytic pickling. Hydrogen is shown to diffuse through the crystals, and permeability is largely dependent on the surface finish of the material.

A Contribution to the Study of Group Blisters. D. G. Evans. (Swansea Technical College Metallurgical Society, Mar. 20, 1937). The author reviews earlier work on the occurrence and causes of blisters in steel sheets, and describes experimental work undertaken to further present knowledge of the phenomenon. It is concluded that, employing the present rolling system, most steels are to a greater or less degree prone to producer blistered sheets, that under appropriate pickling conditions all sheets may be made to blister, and that by the use of effective restrainers the prevention or limitation of blistering is possible on an economic basis.

COATING OF METALS

(Continued from pp. 145 A–148 A)

Fundamental Principles of Metallic Protection. U. R. Evans. (Midland Metallurgical Societies, Mar. 4, 1937 : Journal of the Birmingham Metallurgical Society, 1937, vol. 17, June, pp. 52–67). An account is given of the mechanism of corrosion and of means by which it may be prevented. These are dealt with under the following heads : Impervious coatings, including baking-varnish coats and vitreous enamels; paints, including red-lead and metallic-lead or lead-alloy primers; metallic coatings cathodic towards the basis; metallic coatings anodic towards the basis; oxide coats; phosphate coats; the use of colloids and emulsions as inhibitors; and anodic and cathodic inhibitors.

Electroplating. M. S. Simonds. (Iron Age, 1937, vol. 140, July 29, pp. 24–28). The author reviews the economic aspects of plating, passing subsequently to a discussion on standards adopted for various classes of work. The significance of deposit-thickness is considered from various angles, and some details are given of brush-plating and plating by cathodic sputtering.

Rapid Electrodeposition of Iron. C. Kasper. (United States Bureau of Standards, Research Paper 991 : Metal Industry, 1937, vol. 51, July 2, pp. 19–21). The author describes investigations on the deposition of iron from ferrous chloride solutions at current densities up to 30 amp. per sq. dm. With careful control of the acidity and temperature, relatively soft ductile deposits are obtained.

Special Lighting Requirements for the Testing and Working of Metals. K. Wernicke. (Metallwirtschaft, 1937, vol. 16, Aug. 13, pp. 818–819). The author describes the special lighting requirements for the examination of the finish on, or of defects in, sheet metal. The specialised use of filament lamps is dealt with, including their application in the checking of tin, nickel, or chromium plated sheet for irregularities in the deposit. The mercury discharge lamp is recommended for distinguishing nickel from chromium plate, for estimating the quality of deposits, and, in particular, for examining tinplate in the sorting room. Their use in sheet mills is discussed. The application of sodium lamps is also dealt with.

Measurement of the Thickness of Electrodeposits. (Nickel Bulletin, 1937, vol. 10, June, pp. 121–125). A brief review is given of the purpose and type of nickel underlay for electrodeposited chromium, followed by accounts of various methods, including the B.N.F. jet test, of testing the thickness of the nickel deposit.

The Thickness of the Electroplated Coating and Methods for its Measurement. E. Mills and E. C. J. Marsh. (Engineering, 1937, vol. 144, July 9, pp. 53–56). A preliminary discussion on various

types of electrodeposited coatings and the significance of the thickness of the deposit is followed by a description of the optical projection method, various microscopic methods, chemical stripping methods, and drop or spot tests for determining the thickness of the coating. Data are given in tabular and graphical form.

The Electrolytic Treatment of Metal Surfaces. H. Krause. (Metallwirtschaft, 1937, vol. 16, Aug. 13, pp. 816–817). The author refers to the saving in wear of expensive alloy steel machine components effected by wear-resisting deposits of chromium.

Bright Zinc-Plating Process Produces Brilliant Deposits Directly from Bath. R. M. Drews. (Steel, 1937, vol. 100, June 21, pp. 66–70). A detailed account of the bright zinc-plating process and working procedure as operated in the Bolt and Nut Division of the Republic Steel Corporation is given.

The Reactions of Iron with Molten Zinc. H. Grubitsch and F. Brückner. (Stahl und Eisen, 1937, vol. 57, July 22, pp. 819–820). To confirm the explanation advanced by Musatti and La Falce concerning the erratic results obtained by Grubitsch for the solution of iron by molten zinc, pickled close-annealed specimens of Armco iron were subjected to the action of molten zinc at a constant temperature for periods of 1 to 60 min. Grubitsch's curves are confirmed, and Musatti and La Falce are shown to have obtained erroneous results, owing to unsatisfactory experimental technique.

The Electrodeposition of Tin from Acid Sulphate Solutions. A. W. Hothersall and W. N. Bradshaw. (Electrodepositors' Technical Society: Technical Publications of the International Tin Research and Development Council, 1937, Series A, No. 56: Metal Industry, 1937, vol. 51, Aug. 20, pp. 187–192). The authors describe investigations undertaken to evolve a satisfactory method of electrodepositing tin from acid solution in the form of a thin compact coating suitable for the protection and decoration of metals. The use of certain aromatic addition agents is dealt with.

Variation in Thickness of the Tin Coating of Tinplate, and its Effect on Porosity. W. E. Hoare. (Iron and Steel Institute, Sept., 1937: this Journ. p. 99 P). The general relation of tin coating thickness to porosity has been investigated. It is found that the number of pores per 100 sq. cm. falls from 8000 to 300 as the coating thickness is increased from 1 to 3 lb. per basis box, and falls more slowly from 300 to 2 as the coating thickness is further increased to 15 lb. per basis box. From a consideration of the shape of the tin-yield/porosity curve it is shown that local variation of the coating thickness tends to produce over-sheet increases of porosity.

"Bridging over" of potential sites of normal pores has been established, and the implications are commented upon. The theoretical findings of Chalmers with respect to the minimum pore size possible for any particular coating thickness have been confirmed.

The three orders in which the coating thickness varies are detailed and the corresponding porosity effects are discussed.

A new technique has been evolved, which enables a quick estimation to be made of the presence and type of macroscopic irregularities of coating thickness, and comments are made on the modes of formation of such irregularities. Possibly the most important finding in this respect is that a periodic variation of coating thickness occurs across the direction of tinning (*i.e.*, lines of convexity in the direction of tinning), this periodicity being coincident with that of the grease lines. These periodic variations have been termed *tin ridges*, and their existence has been confirmed by the application of several methods.

By receiving tin from other parts of the surface these ridges cause the tin yield at the corresponding troughs to fall to approximately 60% of the mean value.

The effect of cleaning on porosity has been examined.

Hot-Dipped Aluminium-Coated Sheet. E. J. Groom. (Sheet Metal Industries, 1937, vol. 11, July, pp. 611–613). After a preliminary discussion on the theoretical aspects of hot-dipped aluminium-coating processes, the author reviews the patent literature on the subject and traces the developments which have occurred during the last forty years.

Notes on Some Recent Experiments in Connection with the Spraying of Steel by the Wire-Fed Metal-Spraying Pistol. R. R. Sillifant. (Iron and Steel Institute, Sept., 1937 : this Journ. p. 131 P). Metal-spraying technique, as applied to the re-surfacing and building-up of machine parts, is described. Some experiments in connection with the fuel gases—compressed coal gas, hydrogen and dissolved acetylene—with respect to the deoxidising effects of reducing flames are explained. The use of nitrogen as an impelling medium in place of compressed air, to minimise oxidation, is also described. Further, the results of the heat treatment of sprayed steel, using dissolved acetylene as a fuel gas and compressed nitrogen as the impelling medium, are explained.

Chemical Treatment Retards Rust, Improves Enamel Adherence to Steel. (Steel, 1937, vol. 101, July 19, pp. 61, 64). A brief account is given of the comparative merits of the " Jetal " treatment of steel sheet and other proprietary processes for promoting bonding and corrosion resistance. The phosphate method is noted, but no details of the " Jetal " treatment are specified.

Application of Gas-Radiant Tubes to a Continuous Porcelain Enamelling Furnace. G. M. Parker. (National Conference on Industrial Gas Sales, Chicago, 1937 : Industrial Heating, 1937, vol. 4, July, pp. 556–557). A description is given of the construction of the continuous enamelling furnace installed at the National Enamelling and Stamping Co.'s plant, Granite City, Ill. Special reference is made to the welding of the radiant tubes and to the method adopted for supporting them.

An Industry Comes of Age. Enamellers Meet in Open Forum. C. S. Pearce. (Metal Progress, 1937, vol. 32, July, pp. 42–45).

The chemical and physical properties of the cast-iron or sheet-steel base for vitreous enamelling purposes are discussed, together with cognate properties of the enamels. One-cover coat ware, radiant tube furnaces, and protective devices for the work and the operator are also dealt with.

Integral Expansion of Vitreous Enamels between the Softening Point and Room Temperature. J. E. Rosenberg and A. Langerman. (Journal of the American Ceramic Society, 1937, vol. 20, July, pp. 236–244). The significance of the coefficient of expansion of vitreous enamels in connection with enamelled steel sheet is noted and experimental determinations of the forces involved are described. Graphical data are presented.

The Protection of Pipes in the Soil. H. van der Veen. (Métaux et Corrosion, 1937, vol. 12, May, pp. 96–99). The Corrosion Committee II. of the Dutch Central Corrosion Committee have been studying the protection, by the application of asphalt coatings, of pipes to be buried in the soil. In the present article the author enumerates shortly the three methods used for testing the ability of the asphalt coating to isolate the pipe completely from the action of soil water ((*a*) by immersion in *N*/50 hydrochloric acid, (*b*) by measuring the electrical conductivity of the coating, (*c*) by measuring the insulation property of the coating by applying an alternating high-frequency electric current (at unprotected parts a spark is seen)), and deals briefly with the principal conditions for the production of a good coating, interior protection, the characteristics of a good coating, and the testing of the quality of the asphalt coating.

The Protection of Iron and Steel by Means of Paints. L. A. Jordan and L. Whitby. (Métaux et Corrosion, 1937, vol. 12, Feb., pp. 40–43; Apr., pp. 74–81; May, pp. 100–106). A French translation of an English paper which appeared in the Bulletin of the Research Association of British Paint, Colour and Varnish Manufacturers, No. 16, pp. 11–176.

PROPERTIES AND TESTS

(Continued from pp. 191 A–198 A)

Calibration of Testing Machines under Dynamic Loading. B. Wilson and C. Johnson. (Journal of Research of the National Bureau of Standards, 1937, vol. 19, July, pp. 41–57). The errors of the indicated loads of testing machines used to determine the mechanical properties of engineering materials are usually determined for static loads. Additional errors due to variation in the rate of loading were determined on six machines by means of an elastic calibrating device up to 50,000 lb. per min. Errors were noted which sometimes exceeded the specified tolerances of the machine. It is shown that the results obtained cannot be of general application but, on the other hand, do serve to indicate the magnitude of errors to be expected.

Yield Strengths corresponding to Small Percentages of Set. (American Society for Testing Materials, 1937, Preprint No. 4, pp. 10–14). From the results of investigations undertaken to determine whether the methods recommended for ascertaining the yield strength as given in the "Standard Definitions of Terms Relating to Methods of Testing" (*E* 6–36. 1936 Book of A.S.T.M. Standards, Part I., p. 861, and Part II., p. 1429) should include some method of determining the yield strength corresponding to a very small amount of offset (approximately 0·003%) for which existing methods may not be satisfactory, it is concluded that small offset values are required only for high-quality heat-treated steels or possibly for other materials liable to very high stress, and that offsets below 0·005% are only justified for experimental purposes. There is, therefore, no need for revision of the recommended methods previously cited, which do not cover materials in which very low percentage offset is required, although those in Standard Definition *E* 6 should be of general application.

Report of Research Committee on Yield Point of Structural Steel. (American Society for Testing Materials, 1937, Preprint No. 23). The procedure for and results of investigations on the yield point of mild structural steel are presented, and the significance of this factor to the engineer, the range in yield point when the material is furnished under specification, and the testing methods suitable for a reasonably accurate and inexpensive determination of the yield point are considered.

The Determination of Minute Alterations in Length in Tensile Testing and Particularly in the Fatigue Test. H. Scholz. (Mitteilungen der Kohle- und Eisenforschung G.m.b.H., 1937, vol. 1, June, pp. 171–180). To reduce errors in measurement associated with the use of the Martens mirror extensometer for determining permanent

extensions in the test-piece during tensile or fatigue tests, the author recommends the following precautions be taken: Stresses resulting from the application of graduated straight-edges to the test-piece and stress variations during the course of the test should be excluded; the effect of the weight of the measuring instrument on the measuring process should be removed; temperature differences in the test-piece should be maintained at as low a level as possible by the use of "equalisers" of copper, aluminium or silver. A fatigue-testing apparatus developed by the Vereinigte Stahlwerke A.G. is described, and a frequency curve illustrating observed errors in permanent extension measurements is presented.

Improvement in the Adaptability of the Tuckerman Strain Gauge. L. A. Meisse. (American Society for Testing Materials, 1937, Preprint No. 105). The author describes transfer mechanisms developed for the purpose of improving the adaptability of the Tuckerman optical strain gauge. These consist of the addition of specially constructed parallel flexure plates transmitting the movement from the specimen to the gauge body. Commercial applications of the system to, and the more general use of such transfers in, other types of strain gauges are indicated.

The Evaluation of Impact Tests on Materials of Low Impact Value. F. Uebel. (Giesserei, 1937, vol. 24, Aug. 13, pp. 413–417). The author discusses the energy losses during the testing of brittle and tough materials by impact fracture. Such losses are shown to reside in the kinetic energy acquired by the fractured portion and in forcible contact between the pendulum and the test-piece after fracture. An experimental method of determining the losses is described, in which the broken test-piece is replaced in position and the testing procedure repeated under similar conditions, the resulting energy losses in the pendulum being due only to the factors mentioned above. Experimental losses are shown to be greater than calculated losses. Some data are given for cast iron.

Stresses in Steel. G. W. Austin. (Journal of the West of Scotland Iron and Steel Institute, 1937, vol. 44, Feb., pp. 63–70). The author discusses the elastic and plastic states and their significance and application in the mechanical testing of metals; in connection with the latter property an explanation is given of the stress-strain diagram. A general discussion on testing methods concludes the paper.

The Distribution of Internal Stresses in a Quenched Shaft. U. Dehlinger. (Metallwirtschaft, 1937, vol. 16, Aug. 20, pp. 853–854). The author demonstrates that no contradiction exists between the results furnished by the drilling method and the X-ray method for measuring internal stresses. No modification of the formula of Sachs and Weerts for normal X-ray photographs is justified by the work of Kurdjumow and Scheldak, whose suggested substitute is directly opposed to the laws of mechanical equilibrium.

Stress Measurements on Welded and Cold-Worked Test-Pieces by

Means of X-rays. H. Möller and A. Roth. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 10, pp. 127–130). A method of employing X-rays for stress determinations is described, and an account is given of its application to a welded triangular test-piece of chromium-molybdenum steel tube, to a similar form in carbon steel tube, and to a cold-worked duralumin tube. The significance of stress distribution in welded structures is discussed.

A New Tension-Compression Fatigue Testing Machine. T. Nisihara. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, May, pp. 153–156). The following disadvantages were noted in the electro-magnetically operated tension-compression fatigue machines of Haigh and Schenck: Difficulties arise in repairing when sudden breakdowns occur; the determination of stresses is indirect and calibration is often necessary; the loading capacity of the machine is usually rather low, and only small-diameter test-pieces can be employed; the specimen is fixed at one end, but the parts of the machine stressed in tension or compression usually rotate in one plane. The new machine described avoids these disadvantages, is directly operated by mechanical means and can be made to take test-pieces of any size. Stresses are measured directly. (In Japanese).

Fatigue Testing of Full-Size Components and Structural Parts. A. Thum and G. Bergmann. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Aug. 28, pp. 1013–1018). The authors indicate the necessity for investigation of the mechanical properties of actual structures as opposed to those of test-pieces. Testing and measuring methods for repeated impact are described and some testing machines are referred to. Alternating-stress fatigue testing machines with constant deformation and constant loading are dealt with from the point of view of their applicability under various conditions. A resonance testing machine demanding little power even when testing large structures is also described.

Degree of Fatigue in Carbon Steels under Repeated Bending. F. Ôsiba. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, May, pp. 145–150). The author applies Honda's method in studying the progress of fatigue by repeated bending in Swedish carbon steels. Specimens of uniform diameter show fatigue progressing at a diminishing rate as the number of repetitions under constant load increases, while the final value at the moment of breakdown becomes less with decreased intensity of stress. Under low stresses of a certain type the degree of fatigue may attain an almost constant value, this stress marking the true endurance limit. Notched specimens show fatigue progressing first slowly, then rapidly, and finally slowly with increasing number of stress repetitions; the middle phase is due to the formation of minute cracks. A safe working limit for components with sections changing rather abruptly is that stress intensity causing no progress

of fatigue. The effects of grain size and micro-cracking on the impact value of fatigued material are discussed. (In Japanese).

Fatigue in Shafts under Combined Bending and Torsion. P. L. Capper. (Engineer, 1937, vol. 164, Aug. 6, pp. 150–152). The author investigates fatigue failure in shafts under combined bending and torsion. A simple analysis is presented of the conditions for failure by fatigue under direct and shear stress, and by passing the static elastic limit. Some rules for design are deduced from the results obtained.

Nomenclature for Various Ranges in Stress in Fatigue. (American Society for Testing Materials, 1937, Preprint, No. 25, pp. 2–5). The difficulties entailed in defining precisely the stress range in fatigue when employing the nomenclature at present commonly used in English-speaking countries are noted, and other proposed diagrams for representing the effect of stress range are considered, including those of Goodman (modified), and R. L. Templin.

The Effect of Discontinuities and Surface Conditions on Failure under Repeated Stress. F. C. Lea. (Engineering, 1937, vol. 144, July 23, pp. 87–90; Aug. 6, pp. 140–144). The author reviews previous work on the effect of discontinuities and surface conditions on the fatigue range of metals, and notes the stress concentration caused by such discontinuities. The decreased fatigue range of riveted joints and faulty welds is discussed. Experiments on the effects of corrosive conditions on fatigue are described, and data are presented in tabular and graphical form. Continuity of corrosive action is demonstrated and the results are analysed, while the effects of square and V collars attached to, or forming an integral part of, the test-piece are also investigated from the standpoint of corrosion-fatigue. The effect of variations in surface condition on fatigue in a 0·16% carbon steel are determined, including carburisation, small indentations, grooves, keyways, nickel-plating and holes (these last being determined for 0·19% carbon and high-carbon steels). A comparison is drawn between the theory of, and experimental results on, stress concentration, and tests were carried out on nickel-chromium austenitic steel, drilled plates, and riveted joints. The effects of welding on the strength of joists are noted.

Measurements with a New Scratch-Hardness Testing Machine. K. Sporkert. (Metallwirtschaft, 1937, vol. 16, Aug. 20, pp. 854–859). A new apparatus for determining scratch-hardness according to the method of Martens is described. The scratching device is attached to the microscope and is rapidly replaced by an illuminator for measuring the width of the scratch. Among the materials tested were compacted metals, electrodeposited nickel and chromium, anodic films, nitrided steel, sintered carbides, and glasses. Individual constituents in the structures of metals were also examined. The method yields valuable information on machinability and wear resistance, and may be used on thin films, separate constituents in a structure, and on hard metals. Reasonable accuracy is obtained.

Analysis of the Brinell Hardness Test. R. H. Heyer. (American

Society for Testing Materials, 1937, Preprint No. 108). Certain features of the Meyer hardness test are reviewed, and a method is proposed for expressing a shear yield strength which bears a definite relationship to tensile or compressive yield strengths. Based on relative strengths in shear and compression, an explanation is offered for the commonly observed differences in the surface contours of Brinell impressions. Other differences in the nature of the plastic deformation below the surface of the impression are studied by means of a split hardness test specimen. Relations are established between the depth of visible plastic deformation, the rise of the metal above the original surface, and the n coefficient of Meyer. The rate of increase of the depth of plastic deformation with the diameter of the indentation is determined for four series of metals. Published work on the thickness requirements for testing are reviewed in the light of the present research. Plastic deformations under cylindrical and spherical indentors are compared.

Hot Hardness. J. H. Hruska. (Iron Age, 1937, vol. 140, July 15, pp. 30–34). The author discusses briefly the development of hardness testing methods, and describes certain of them. The use of tungsten carbide indenting tools for hot-hardness determinations is described, and graphical and tabular data are presented for various metals and alloys, including plain and alloy steels. Certain aspects are considered from a mathematical standpoint.

Some Notes on Age-Hardening. R. Higgins and D. L. Phillips. (Swansea Technical College Metallurgical Society, Mar. 20, 1937). The authors discuss the occurrence and causes of age-hardening in certain non-ferrous metals and in steels. In connection with the latter the various factors controlling the process are treated in detail, and the phenomenon of temper-brittleness is noted, together with those of blue-brittleness and stretcher-strains.

Wear Test Procedure Gives Duplicable Results—Lists Good and Poor Irons. (Iron Age, 1937, vol. 140, July 15, pp. 55–56). An abstract of a paper by P. S. Lane presented to the American Foundrymen's Association. (*See* p. 194 A).

Wear Testing. S. J. Rosenberg. (Metal Progress, 1937, vol. 32, July, p. 65). The author discusses the interpretation of the term "wear," and comments on the tests developed by Freeman, and Freeman and Clark.

Metal Consumption in Hammer Mills at Norris Dam. F. Cadeno. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 824; Mining Technology, 1937, vol. 1, July, No. 4). The author presents data relating to three specific instances in connection with the production of various aggregates used in the construction of the Norris Dam. The relation of the silica content of the rock to hammer-wear in the mills employed for crushing it is discussed, the relative costs of slugger and stirrup hammers are compared, and the comparative cost of tool steel and manganese steel grate-bars is noted.

The Magnetic Quality of Cobalt, Nickel, and Iron. T. F. Wall. (Engineer, 1937, vol. 163, Apr. 2, pp. 397–398). The author describes an investigation to determine the effect on the maximum permeability of ferromagnetic materials when maintained at a high temperature in hydrogen and at the same time carrying an electric current at high density. Magnetisation curves for cobalt and nickel indicate that, after "flashing," permeabilities of 340 and 1400 respectively are obtained for these metals, while corresponding maxima previously recorded are 175 and 1120. The value of the maximum permeability of iron as received was 700; after "flashing," it rose to 3500. Curves show that the maximum permeability of iron rises at a slower rate than that of nickel.

An Investigation of Some Magnetic Alloys. T. Nishina. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 344–361). The author records the investigation of the magnetic properties of a large number of alloys of various compositions. New alloys of scientific and industrial importance were discovered, possessing high initial permeability with or without high electrical resistivity, and constant permeability up to a moderate field strength. Cuper-permalloy Nos. 1, 2, and 3 are described, together with Resisto-permalloy, compositions being indicated in each case. The technique of preparing the alloys for the investigation is described.

The Theory of Hysteresis Loss in Ferromagnetic Metals under Strong Elastic Stress. N. S. Akulov. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 271–282). Mathematical treatment of the effect of elastic stress on hysteresis loss shows why the theory of Becker does not cover the influence of weak stresses, although it yields comparatively good results for very high elastic stress. The author concludes with an account of the rôle of inversion and of its general formulation; from his equations he shows how the high coercive force of the alloys of Honda and Mishima can be explained.

The Hysteresis Loop and Magnetostriction of the Iron Crystal. S. Kaya and H. Takaki. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 314–328). In order to determine accurately the constants of magnetostriction, the remanence and saturation points were chosen as normal conditions. From the constants determined in this way, the distribution of the elementary fields was calculated for six principal orientations.

The Elastic Deformation of Ferromagnetism. F. Bitter. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 228–234). The author introduces the concept of elastic deformation of a vector field and derives differential equations governing the behaviour of a simple model. A particular solution is given and discussed in relation to the problem of ferromagnetism. It is shown that elastically distorted spontane-

ous magnetisation can describe ferromagnetism as well as the usually assumed "fields of spontaneous magnetisation," and that the regular powder patterns observed on single crystals may be due to the elastic deformations discussed.

On the Hysteresis of Magnetostriction of Iron, Nickel, Cobalt, and Single Crystals of Iron. Y. Masiyama. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, June, pp. 1–39). The hysteresis of the magnetostriction caused by a cyclic change of the magnetic field for iron, nickel, cobalt, and single crystals of iron, was determined by varying the field gradually or suddenly; in the latter case, the residual elongation is greater than in the former, when the field is reduced to zero. Single crystals show a small hysteresis and a similar behaviour with gradual or sudden variation of field. The anomaly is explained by the conception of inertia in the angular motion of the elementary magnets.

On the Hysteresis of Magnetostriction for Alloys of the Systems Iron-Nickel, Nickel-Cobalt, and Iron-Cobalt. Y. Masiyama. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, June, pp. 65–85). In all alloys of the iron-nickel, nickel-cobalt, and iron-cobalt systems, the ascending and descending branches of magneto-striction curves plotted against magnetising fields each show maxima in weak fields slightly displaced from the zero field position. Alloys with 20, 50 and 70% of iron exhibit minima at zero field.

On the Effect of Temperature on the Discontinuous Process of Magnetisation in Nickel, and Nickel-Iron Alloy (40% Ni). M. Takagi. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, June, pp. 55–64). In the case of a nickel-iron alloy containing 40% of nickel, the discontinuous process of magnetisation decreases approximately linearly with rising temperature. The prominent discontinuous jumps in strained materials shift usually to weaker, but sometimes also to stronger fields.

On Gerlach's Thermomagnetic Electromotive Force in Nickel, Iron and Nickel-Iron Alloys. N. Yamanaka. (Science Reports of the Tôhoku University, 1937, vol. 26, June, pp. 40–47). Gerlach's thermomagnetic electromotive force was determined in nickel-iron alloys of various compositions, and its dependence on the applied magnetic field, temperature gradient, composition, and thermal treatment of the specimens was studied.

On the Effects of Stress on Gerlach's Electromotive Force in Nickel, Iron, and Nickel-Iron Alloys. N. Yamanaka. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, June, pp. 48–54). A study of the effects of tension and torsion on Gerlach's thermomagnetic electromotive force in nickel, iron, and nickel-iron alloys is presented.

Report on Long-Time Creep Tests of 18 per cent. Chromium, 8 per cent. Nickel Steel and 0·35 per cent. Carbon Steel. H. C. Cross and J. G. Lowther. (American Society for Testing Materials, 1937, Preprint No. 24, pp. 15–23). A continuation of previous work,

undertaken to procure data for comparisons of creep rates over short and long periods of time. (*See* Journ. I. and S.I., 1937, No. I., p. 289 A).

Discrepancies in the Load-Carrying Abilities of Carbon Steels at 850° F. H. W. Gillett. (American Society for Testing Materials, 1937, Preprint No. 24, pp. 24–28). The author reviews investigations on the mechanical characteristics of carbon steels (0·15–0·40% carbon) at high temperatures, and discusses the results obtained. Tabular data are presented, and the need for greater refinements in methods of creep-testing and greater knowledge of the effects of complex stresses is indicated.

Thermal Autostabilisation of the Velocity of Imposed Elongation and the Establishment of Diagrams Characterising Flow. G. Ranque. (Revue de Métallurgie, Mémoires, 1937, vol. 34, June, pp. 349–360). The author describes the aims and principles of thermal autostabilisation and its application. Calculations and experimental results are presented, and elongation and recrystallisation are discussed. Carbon steel with a small addition of vanadium, and a high-duty steel for forging purposes, containing 4·5% of chromium, 0·65% of molybdenum and 0·70% of vanadium, are dealt with.

On the Measurement of Young's Modulus of Elasticity of Iron, Nickel, and Cobalt at High Temperatures. K. Nakamura. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 146–157). By measurements of the natural period of longitudinal vibration of the specimens, certain difficulties in the determination of Young's modulus leading to disagreement among the results obtained by previous workers have been overcome. The elastic moduli of iron nickel and cobalt were also measured at high temperatures and in a constant magnetic field. The allotropic transformation of cobalt and the magnetic transformation of nickel are shown to yield anomalies on the modulus-temperature curve within the range of experimental temperatures.

Embrittlement of Steels at High Steam Temperatures. J. H. G. Monypenny. (Metal Progress, 1937, vol. 32, July, pp. 67–68). The decrease in toughness of many types of steel when exposed for long periods to temperatures of 800–900° F. in steam plant is noted, with special reference to bolts and studs exposed to full steam temperature. Such components are usually of alloy steels, but even so they show greatly decreased impact values after a few months use. The author considers the cause of the embrittlement and means of preventing it, and the practical significance of the low impact value.

The Diffusion of Gases through Metals. (Metallurgist, 1937, vol. 11, June 25, pp. 35–37). A review is given of the work of Smithells and Ransley on the diffusion of gases through metals. (Proceedings of the Royal Society, 1936, A, vol. 155, p. 195). The investigations comprised the de-gassing of commercial nickel, the

diffusion of carbon monoxide through nickel, and the diffusion of carbon and oxygen through nickel. The authors' experimental technique is described, and the work of Ham on the diffusion of hydrogen through nickel and iron is noted.

Gases in Ferrous Materials. H. Ellis. (Iron and Steel Industry, 1937, vol. 10, June, pp. 487–491). The author discusses the effects of gases in steels, and, in particular, the embrittling influence of hydrogen and the decrease in corrosion resistance due to nitrogen. (*See* Journ. I. and S.I., 1937, No. I., p. 141 A).

The Effect of Hydrogen on Steel. (Metallurgist, 1937, vol. 11, June 25, pp. 40–43). A review of the work of P. Bardenheuer and E. H. Keller on the influence of hydrogen, absorbed in melting, on steel. (*See* Journ. I. and S.I., 1937, No. I., p. 212 A).

Effect of Hydrogen under High Pressure on Unalloyed Steel. F. K. Naumann. (Stahl und Eisen, 1937, vol. 57, Aug. 12, pp. 889–898). After a preliminary discussion on the manifestation and effects of attack by hydrogen as exemplified by affected components of a high-pressure hydrogenation plant, the author describes investigations carried out to determine the influence of pressure, temperature and time on the initiation and progress of decarburisation in unalloyed steels. The onset of attack depends not only on the pressure and temperature but also on the duration of the test. If attack has begun after the lapse of the period characterised by the resistance to the effects of hydrogen, it rapidly penetrates the steel. At low temperatures (400–500° C.) decarburisation is incomplete and proceeds in a branch-like form from the grain boundaries and certain preferred surfaces into the crystal grain. The dendritic axes are more quickly decarburised than the remainder of the material, and cold-working favours attack. The strength and particularly the toughness are greatly diminished; even Armco iron, in spite of its low carbon content, is susceptible to attack. Phosphorus, sulphur and oxygen are not removed, even under conditions where decarburisation has already begun. Nitrogen is partly removed before the onset of decarburisation, without affecting the toughness. Hydrogen attack is strongly differentiated from normal low-pressure decarburisation, the first process being characterised by the formation of methane, the second by the production of carbon monoxide.

The Investigation of Material as a Basis for Construction. M. Ude. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81. Aug. 7, pp. 929–934). The significance of investigations of the strengths of structural materials is dealt with in the form of an historical review, the author subsequently discussing the present and future possibilities and applications of such investigations in regard to structural engineering.

Progress Made in Automotive Cast Irons. H. S. Austin. (American Society for Metals: Foundry, 1937, vol. 65, June, pp. 22–23, 71–72). The author describes the classification of cast irons

for use in automobile engineering, details their physical, mechanical and chemical characteristics, and examines melting practice and cupola design.

Methods of Obtaining Cast Iron Resistant to High Temperature. A. Dawans. (Association des Ingénieurs sortis de l'École de Liége : Revue Universelle des Mines, 1937, vol. 13, July, pp. 281–291). The author discusses the causes of failure in castings subjected to high temperatures, such as growth and corrosion, and the means of conferring resistance to breakdown, for example, by alloy additions and by the provision of protective coatings. The failure of components under thermal shock is dealt with at the conclusion of the article.

The Selection of Steels for Service. R. T. Rolfe. (Iron and Steel Industry, 1936, vol. 10, May, pp. 379–383; July, pp. 523–527). The author examines the analysis of mechanical test results as a criterion of the quality or adaptability of a steel. Various mechanical properties are considered in detail, discriminating tests are noted, the application of steels for various duties is considered and tabular data presented. The uses for which carbon steels are not fitted are discussed together with the essentials governing the choice of these or alloy steels.

Steels in Automobile Construction. T. Swinden. (Institution of Automobile Engineers : Iron and Steel Industry, 1937, vol. 10, June, pp. 492–496; July, pp. 528–530). (*See* p. 39 A).

Influence of the Cast Structure on the Mechanical Properties of Hot-Worked Steel. K. Kornfeld. (Stahl und Eisen, 1937, vol. 57, Aug. 5, pp. 870–873). The author describes investigations of the mechanical properties of chromium and nickel structural steels and compares such properties at the core and at the outer zones of ingots. Data are presented in tabular form, and it is shown that the mechanical properties are strongly influenced by the structure of the material in the cast state, altering according to the primary structure across the section. The impact strength increases markedly towards the centre of the billet, whilst the elastic limit and tensile strength fall slightly.

Chrome-Molybdenum Carburising Steel Cuts Production Costs. (Steel, 1937, vol. 101, July 12, pp. 70–71). The structural and mechanical advantages of chromium-molybdenum steels in the construction of hypoid gears for automobiles are described. The low distortion of such steels during treatment is referred to.

A Digest of Stainless Steels. V. N. Krivobok. (American Iron and Steel Institute, May 27, 1937). The author discusses the commercially available stainless steels and evaluates their mechanical properties under different conditions and their physical and corrosion-resisting properties. The appropriate materials for a number of given applications are suggested.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 199 A–204 A)

Physical Methods of Metallurgy. B. Chalmers. (Metal Industry, 1937, vol. 50, May 28, pp. 597–600; June 11, pp. 645–648; vol. 51, July 9, pp. 31–34; Aug. 6, pp. 135–138). The author describes the application of modern physical methods to metallurgical problems. Optical interference, electron diffraction, X-ray methods and other applications are dealt with.

On the Resolving Powers of the Infinity Objectives of N.A. 1·40, and N.A. 1·60 Used with a Precision High-Power Metallographic Microscope. F. F. Lucas. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 614–635). In this thesis a new precision-type metallographic apparatus, using infinity-corrected objectives of N.A. 1·40 and N.A. 1·60, is discussed. The latter are mono-brom-naphthalene immersion objectives. Comparison is made between photographs obtained with the apochromats of N.A. 1·40, and the special immersion type of N.A. 1·60. Detail may be resolved down to 200 atomic diameters. The technique employed is discussed.

Erroneous Interpretations of Studies under Polarised Light. A. M. Portevin. (Metal Progress, 1937, vol. 32, July, pp. 63–64). Spurious bi-refringence is claimed by the author to be the cause of the black cross observed by Moll and Schafmeister in amorphous globular silicate inclusions in steel, the cause of which these authors attributed to stresses in the inclusions.

The Measurement at Half Maximum Intensity of X-Ray Interference Fringes. H. Möller and A. Roth. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, pp. 123–126). The relationship between the electrometer reading, the darkening of the film and X-ray intensity is proved, by means of a Zeiss registering photometer, for Agfa-Laue film moistened on one side and exposed to cobalt radiation. Photometer curves were transformed into X-ray intensity curves, and from these the widths at half maximum intensity of interference fringes were calculated to an accuracy of $\pm$ 0·1 mm. independent of the exposure time; measurement of the widths directly from the photometer curves only gave correct results when the darkening did not exceed 0·7. Between the temperature limits of 17° C. and 22° C. investigated, and with a tank developer stable for 2–3 months, variations in developing temperature and the condition of the developer do not affect the conversion. Errors in repeated determinations are less than those in the evaluation method.

Scattering in the Near Infra-red. D. L. Gamble and C. E. Barnett. (Industrial and Engineering Chemistry, Analytical Edition,

1937, vol. 9, July 15, pp. 310–314). The authors describe a method based on infra-red (and visible) transmission of powder-suspensions, by which to determine the particle size and particle-size distribution of powders. Pigments for rubber are specifically referred to.

An Improved Magnetic Rail Defectoscope. M. Suzuki. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 409–417). The author deals with an improved form of magnetic device for detecting defects in rails. A recording apparatus has been devised which operates through the medium of induced currents; curves may be recorded directly, and transverse fissures, abnormal stresses and segregates accurately located.

An Improved Method of Studying Inclusions in Alloy Steels. W. A. Hare and G. Soler. (Metals and Alloys, 1937, vol. 8, June, pp. 169–171). A method is described of studying the inclusions present in certain alloy steels, in which the analyses and mineralogical phases present are determined by chemical and petrographic means, with X-ray examination in addition, if necessary. The value of the information obtained to the steelmaker is noted.

Statistical Investigations of Structure. III.—Velocity of Crystallisation and of Nucleus Formation during the Transformation of Austenite into Pearlite. E. Scheil and A. Lange-Weise. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 93–95). The continuation of a series of articles (*see* Journ. I. and S.I., 1937, No. I., p. 184 A). By counting the number of pearlite crystals visible in a microsection and calculating the volumetric size and number, the rate of crystallisation and the tendency to form nuclei of pearlite were determined; a steel containing carbon 0·93%, silicon 0·07%, manganese 0·25%, phosphorus 0·014%, sulphur 0·02% and copper 0·22% was used. From experiments made by Wever and Engel the magnitude of the maximum rate of crystallisation and of nucleus formation and the temperature of their occurrence were estimated. The crystallisation velocity is small, but the rate of nucleus formation is, on the contrary, very great. A reduction of the rate of formation of pearlite seems possible by a planned investigation of the inoculating influence of materials. The number of nuclei and the inoculation period are not constant, but depend very much on the degree and period of heating in the γ range.

The Effect of Decarburization on the Microstructure of Quenched High-Speed Steels. T. Murakami and A. Hatta. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 882–895). In the microstructure of high-speed steel quenched from a high temperature, such as 1300° C., the troostitic structure is often observed in the decarburised zone. In order to elucidate the formation of this structure, a sectional diagram for constant contents of 18% of tungsten and 4% of chromium and varying carbon content was constructed by means of thermal

and microscopic analysis and differential dilatometric measurements. The troostitic structure also appears in low-carbon high-speed steel cooled from the melt, owing to the occurrence of a eutectoid reaction $\gamma \longrightarrow \alpha + \eta$ in a temperature range below 1340° C. (a peritecto-eutectic point). The occurrence of the structure in the decarburised portion of quenched high-speed steel is attributed to a similar reaction taking place during rapid cooling.

Microscopic Imperfections in Metallic Crystals. N. P. Goss. (Metal Progress, 1937, vol. 32, July, pp. 41, 80). The author describes briefly the evolution of modern theories of the structure of crystals, and discusses in particular the mosaic structure.

The Influence of Tensile Loading During the Transformation of Martensite on the Structure of An Iron-Nickel Alloy. G. Wassermann. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 89–92). Research on the structure of a 30% nickel-iron alloy in the form of sheet, in which the crystal grains were mainly orientated in one direction (cube formation) indicate that at the γ–α transformation needles are formed, the long axes of which are at $\pm$ 17·0° to the axis of the cube. If, during the transformation, the alloy is stressed in tension in the direction of the cube axis, the structure alters, and in place of the needles lying at 17°, others at $\pm$ 56° to the direction of loading appear in increasing quantities as the stress is increased. Test-pieces loaded in a direction less than 45° from the cube axis exhibit needles at an angle of 25° to the side of the cube. X-ray determination of the orientation of the martensite needles was not possible, owing to heavy deformation of the test-piece, but the equal orientation of $(111)_\gamma$ with $(110)_\alpha$ persisted in all cases. Test-pieces with long axes lying between 0° and 45° to the axis of the cube exhibit a re-orientation of the cubes to their original positions on reversion to the γ state, even when previously subjected to heavy loading and having undergone considerable elongation both before and during the transformation. The expansion occurring during the transformation is apparently effected by crystallographic processes and the transformation itself is probably affected by a superposed tensile load. The formation of martensite under tensile loading is possibly accompanied by a particularly large expansion. It is shown that the expansion may be caused by stresses in the residual austenite. Research on polycrystalline wires showed that during the γ–α transformation expansion phenomena dependent on the superposed tensile load appeared.

Some Experiences with Austenitic Cast Iron. (Foundry Trade Journal, 1937, vol. 57, July 1, p. 9). A note is presented on the practical significance of the austenite $\longrightarrow$ martensite transformation due to immersion in liquid oxygen of an iron of the following composition: Total carbon 3·4%, silicon 1·6%, sulphur 0·1%, phosphorus 0·8%, manganese 0·7%, nickel 14%, chromium 3·2%, and copper 6·8%.

The System Cu-Fe-S. H. E. Marwin and R. H. Lombard.

(Economic Geology, 1937, vol. 32, Mar.–Apr., Supplement to No. 2, pp. 203–284). The authors show that if granular mixtures of the two binary compounds lowest in sulphur—cuprous sulphide and ferrous sulphide—are heated in sulphur vapour to a point approaching fusion, they gradually take up sulphur, each giving rise to a sulphur-rich solid solution, while adjacent grains exchange copper and iron, forming copper-rich and iron-rich ternary solid solutions. These ternary solid solutions react to produce an intermediate compound which also forms a range of solid solutions. Finally with decreasing temperature and increasing pressure such solid solutions break down progressively into more definite compounds richer in sulphur, the ultimate product being a mixture of cupric sulphide and FeS_2. The temperature range employed in the experiments was 400–950° C., and the pressure range 2–760 mm. of mercury.

The Ternary System FeO–Al_2O_3–SiO_2. R. Hay, J. White and T. H. Caulfield. (Journal of the Society of Glass Technology, 1937, vol. 21, June, pp. 270–280). The diagram for the FeO–Al_2O_3–SiO_2 system has been constructed from thermal and microscopical data; the molybdenum wire wound furnace used and the technique employed for obtaining the curves are described. Four ternary combinations are shown to occur, together with three ternary eutectic points closely allied in composition to fayalite. The significance of the deep narrow trough running behind the silicon-rich region of the ferrous oxide–silica system is noted.

A Metallographic Study of the Action of the Cementing Materials for Cemented Tungsten Carbide. S. Takeda. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 864–881). The equilibrium diagrams of the cobalt-tungsten-carbon and nickel-tungsten-carbon systems were determined, and by means of these diagrams and that of the iron-tungsten-carbon diagram, the sintering mechanism of cemented tungsten carbide is clarified. The quality of nickel, cobalt, and iron as cementing materials for tungsten carbide is discussed, and the reasons for the superiority of cobalt are demonstrated.

CORROSION OF IRON AND STEEL

(Continued from pp. 205 A–206 A)

The Corrosion Problem and the Engineer. F. Hudson. (Metallurgia, 1937, vol. 16, June, pp. 51–54; July, pp. 85–88). The author discusses factors affecting the corrosion of metals which are intimately associated with the specific properties of the metal itself or with service conditions. The prevention of corrosion is dealt with in conclusion, particularly in connection with iron and steel structures exposed to attack by sea and fresh waters.

Film Formation in Corrosion Processes. W. H. J. Vernon. (Chemistry and Industry, 1937, vol. 56, Aug. 21, pp. 751–755). The author indicates the general lines on which the mechanism of film formation must be considered in relation to corrosion phenomena. Air-formed oxide films and precipitated films of hydroxide are dealt with.

The Application of Potentiometric Methods in the Study and Predetermination of the Corrosion of Ferrous Alloys. H. Thyssen and J. R. Maréchal. (Revue Universelle des Mines, 1937, vol. 13, July, pp. 310–312). The authors present an analysis of the work of Guitton on the potentiometric determination of the resistance to corrosion of metals subjected to attack by acid solutions. It is apparently possible to derive from Guitton's curves an estimate of the corrosion of a specimen after the lapse of a pre-determined period of time. Nevertheless, certain cases of passivity and activity have been disclosed to which Guitton's findings are not applicable.

The Corrosion of Low-Copper Content Cast Iron by Dilute Sulphuric Acid. J. R. Maréchal. (Bulletin Scientifique de l'Association des Élèves des Écoles Spéciales : Foundry Trade Journal, 1937, vol. 57, Aug. 12, p. 125). The author examines the behaviour of low-copper cast irons exposed to attack by sulphuric acid of various concentrations. Irons containing varying copper contents and 3·4% of total carbon, 2·0% of silicon, 0·47% of manganese, 0·1% of sulphur, and 0·1% of phosphorus, prepared in a pulverised-fuel-fired rotary furnace, were employed in the tests. Corrosion curves are presented and analysis given.

Initial Corrosion Rate of Mild Steel. C. W. Borgmann. (Industrial and Engineering Chemistry, 1937, vol. 29, July, pp. 814–821). A study is presented of the specific influence of the cation on the initial corrosion of mild steel in aqueous solutions. In many solutions the corrosion rate is controlled by the cathodic reaction, and the corrosion process is strongly affected in such cases by the cation. If the anion in neutral solutions is non-oxidising and non-reducing, and forms soluble primary products with the metal, the rate of corrosion depends on the cation; some influence is also

noticed in the case of salts which hydrolyse to give acidic reactions. The influence of the addition of one salt to another, the anion concentration remaining constant, was studied for solutions of the chlorides of potassium, calcium, and ammonium. It is indicated that the initial corrosion of zinc is influenced by the nature of the cation present.

The Influence of Damp Steam in the Low-Pressure Stages on the Operation and Construction of Turbines. H. Paul. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Aug. 28, pp. 1004–1006). The errosive effects of damp steam on various steels employed in turbine rotor construction are noted. Nickel steels and 13% manganese steel are referred to.

Increasing the Corrosion-Fatigue of Steel in Sea-Water. A. Junger. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Aug. 14, pp. 974–975). (*See* Journ. I. and S.I., 1937, No. I., p. 188 A).

A Thermodynamic and Colloidal Interpretation of Published Studies on the Corrosion Cracking of Stressed Mild Steel in Water Solutions. J. A. Tajc. (American Society for Testing Materials, 1937, Preprint No. 97). Assuming that at elevated temperatures solutions of sodium hydroxide and silica produce mainly intercrystalline cracking of mild steel, it is shown that colloidal as well as electrochemical phenomena are involved. Thermodynamic calculations are presented to elucidate problems of the spontaneity of corroding reactions of iron in water and the acceleration of corrosion by sodium hydroxide. The inadequacy of the hydrogen embrittlement theory to account for caustic embrittlement is discussed, and a colloidal explanation is advanced. The peptisation of iron oxide by silica to protect the ferrite grains, thus permitting corrosion along the grain boundaries, is considered.

High Chromium Irons and Steels. E. Maurer. (Metal Progress, 1937, vol. 31, May, pp. 535–536). After a preliminary review of the patent situation in regard to stainless steels in Germany and America, the author quotes F. Rapatz regarding the relative merits of titanium and tantalum as alloying elements in stainless steels and the effect of these additions on the welding, working, and corrosion resistance of the steels. The applications of the nickel-free chromium steels are discussed and the uses of the new alloy "Roneusil" (manganese 16%, chromium 7–9%, molybdenum 1·0%) are indicated.

Titanium does not Increase Corrosion of 18–8 Stainless Steel. W. B. Brooks. (Metal Progress, 1937, vol. 32, July, p. 68). The author refutes a statement quoted by E. Maurer (*see* preceding abstract) that titanium or tantalum cause increased corrosion of, or lead to the formation of a troublesome thin scale on, 18/8 stainless steels.

MINERAL RESOURCES

(Continued from p. 164 A)

Manganese Ore Resources of Portugal and Southern France. (Archiv für Lagerstättenforschung, 1936, No. 63; Stahl und Eisen, 1937, vol. 57, Aug. 12, p. 902). An account is given of the manganese ore resources of South-east Portugal and of Southern France. The geology, chemistry and distribution of the ores are discussed.

Ore Resources of South-East Europe. (Montanistische Rundschau, 1937, vol. 29, Oct. 1, pp. 9–10). Reference is made in this article to exports of iron ore from Jugoslavia and to nickel mining in Bulgaria.

Molybdenum Deposits in France. V. Charrin. (Génie Civil, 1937, vol. 111, Sept. 4, p. 216). The author discusses the distribution and production of molybdenum-bearing minerals in France.

The Ural-Kuznetsk Combine. (Metallurgia, 1937, vol. 16, July, pp. 101–102). A description is given of the aims and activities of the group of interrelated enterprises controlling iron ore deposits in the Urals and coal deposits in the Kuznetsk Basin. The distribution of iron ores is dealt with and the occurrence of nickel and chromium noted. Developments in the Magnitogorsk Combine are dealt with.

Geology and Fuel Resources of the Southern Part of the Oklahoma Coalfield. Part 2 :—The Lehigh District, Coal, Atoka, and Pittsburgh Counties. M. M. Knechtel. (United States Geological Survey, 1937, Bulletin 874-B). Two valuable coal beds, the Lower Hartshorne and Lehigh beds, occur in the Lehigh district; both have been mined, but the latter has yielded more coal. The beds range in thickness from 3 ft. 4 in. to 5 ft. The coal from the Lehigh bed is classified as high-volatile bituminous. No oil has so far been discovered in the district. Gas has been found, but not marketed.

The Conception "Canga." F. W. Freise. (Zeitschrift für praktische Geologie, 1937, vol. 45, Aug., pp. 135–138). The author discusses the geology of "canga." Reference is made to the deposits in the Minas Geraes (Brazil) containing 44–46% of iron, and to other types containing manganese.

The Mineral-Economic Basis of Japan's War in China. E. Schultze. (Metallwirtschaft, 1937, vol. 16, Sept. 17, pp. 960–962). Reference is made to the extent and distribution of Japan's domestic iron ore resources and to possible extensions of such resources in China.

ORES, MINING AND TREATMENT

(Continued from pp. 121 A–122 A)

The Magnetising Roasting of Iron Ores by the Process of the Kaiser-Wilhelm-Institut für Eisenforschung. W. Luyken. (Stahl und Eisen, 1937, vol. 57, July 22, pp. 805–812). Consideration of the older processes of magnetising roasting and of the concentration obtained by their aid, has led to the development of a new method of roasting and concentrating in which the ferromagnetic ferric oxide is produced. The scientific bases of the process were investigated, and laboratory tests confirmed by others on a semi-industrial scale, employing a 5-m. rotary kiln and two different limonites. Conditions were varied during these tests to determine the effect of such variations on the concentration process. Magnetic separation of pulverised roasted ore gave excellent results. A discussion on special points connected with the process follows, including fuel consumption and the ultimate yield of iron.

Experimental Beneficiation of Michigan Iron-Bearing Formations. F. J. Tolonen. (Mining and Metallurgy, 1937, vol. 18, Sept., pp. 422–424). Michigan iron-bearing formations contain sulphur, silica and phosphorus in objectionable amounts, which increase the metallurgical difficulties of extraction and affect the value of the ore derived from them. The narrow margin between mining costs and the value of the product indicates that the cheapest methods of ore dressing are most likely to be adapted for beneficiation. Leaching and sintering are possible methods of removing sulphur, and gravity concentration is possible in certain cases where high silica occurs. Leaching experiments with various solutions show that the phosphate minerals in the ores are very insoluble, and that their removal by this method is impractical. Flotation tests, however, are more promising, and indicate the existence of several different types of phosphate which are difficult to distinguish petrographically. Such a distinction is necessary if the flotation method is to be successful, and chemical and X-ray methods are now being tried. In connection with the removal of silica, graphical data are presented to illustrate the degree of liberation obtained by crushing to $\frac{1}{2}$ in. and $\frac{1}{16}$ in., respectively.

The Process of Magnetic Separation. (Steel, 1937, vol. 101, Sept. 13, pp. 65–68). The chief uses of the magnetic separator are discussed, and tabular data presented regarding ores amenable to magnetic treatment. Various types of magnetic separator are examined, including wet-type machines. The choice of suitable machines for a given job is briefly dealt with.

REFRACTORY MATERIALS

(Continued from p. 215 A)

Notes on the Mechanical Properties of Refractory Materials. A. L. Roberts. (Transactions of the Ceramic Society, 1937, vol. 36, Aug., pp. 326–339). By somewhat detailed consideration of the mechanical properties of refractory materials the author demonstrates the necessity of a range of tests in order to evaluate mechanical properties over a wide range of temperature. Up to 1000° C., the modulus of elasticity and ultimate strength are of primary interest; above this temperature these values cannot be determined, owing to the influence of the time-factor, which must, therefore, be taken into account at high temperatures.

The Physical Properties of Some South African Raw Materials for Silica Bricks. V. L. Bosazza. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 37, June, pp. 590–602). Chemical and mineralogical examination of various South African raw materials appears to indicate that for purposes of silica brick manufacture the order of merit is as follows : Surface quartzites of low opal content, cherts, fine-grained quartzites of the Pretoria series, argillaceous sandstones or gannister, coarsely crystalline quartzite and vein quartz.

Effect of Alkalis on Refractories. F. Hartmann. (Stahl und Eisen, 1937, vol. 57, Sept. 16, pp. 1017–1021). Even at relatively low temperatures the fine matrix of silica refractories is slightly altered and partially dissolved at the surface by alkali vapours; large quartzite crystals exhibit better resistance, and tend therefore to retain their form and strength. Fireclay exposed to alkali vapours at 1000° C. suffers extensive deep softening, and is easily distorted. In contact with molten alkali, a glassy slag film forms on the surface of fireclay and blow-holes are produced. Magnesite refractories are fairly resistant to both molten and gaseous alkali. Magnesia-chromite refractories, on the other hand, suffer intense attack, owing to the alkali reacting with the chromium oxide. Bauxite refractories swell strongly in alkali vapour, owing to the formation of an alkali-aluminium silicate. The lining of a ladle made with plastic clay was rendered useless by molten soda, owing to the formation of fine cracks, but by the choice of a suitable clay with a low alumina content the attack could be minimised. The magnesite refractories of a mixer were found to suffer an increasing attack by alkali-bearing slags as the alkali content increased, but with high manganese and iron such slags became more viscous and less reactive towards the refractories. It is shown that slags are proportionately more reactive according to their fluidity at any given temperature. Highly basic slags resembling blast-furnace slags could not be made appreciably less viscous by additions of soda.

FUEL

(Continued from pp. 216 A–218 A)

The Influence of the Mixing Process on the Combustion of Gas and Air in Furnaces. Parts III A and III B. K. Rummel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 67–80; Sept., pp. 113–123). A continuation of previous articles (*see* p. 166 A). The author describes work carried out in specially constructed experimental apparatus on the mixing of gas and air streams; for "gas," air containing 0·5% of hydrogen was employed. The relationship between the mixing factors and the composition of the gas mixture is discussed, together with the influence of the dimensions of the open-hearth furnace, furnace charge, velocity, inclination and deflection of the gas streams. Burner forms are shown to be governed by furnace design, and the degree of turbulence in the gases prior to emerging from the burner and "dead" spaces in the combustion space are also shown to influence the course of combustion.

On the Concept of Apparent Specific Heat and its Application to the Calculation of Flame Temperatures. Ribaud. (Chaleur et Industrie, 1937, vol. 18, June, pp. 235–246; July, pp. 295–306). The author defines the term "apparent specific heat" in the case of gases capable of dissociating (CO_2, H_2O). Tables are given of apparent specific heats and true specific heats for molecules of H_2O and CO_2 under the conditions obtaining in industrial plant, and the method of employing such data in calculations relating to the combustion of simple gases such as carbon monoxide and hydrogen in air is examined. The direct determination of flame temperatures is also discussed.

Analyses of Coal and Other Solid Fuels, 1934–1936. J. H. H. Nicolls and C. B. Mohr. (Canada, Bureau of Mines, 1937, No. 779). Analyses of Canadian and other coals, anthracites, "slack," peats, wood, petroleum and low-temperature cokes, and various types of briquettes are presented in tabular form.

Studies on the Reactivity of Lignites to Permanganate. Gauzelin and Crussard. (Revue de l'Industrie Minérale, 1937, No. 398, Aug. 1–15, Mémoires, pp. 373–402). The authors examine the effects of acid and alkaline permanganate on lignites of various origins, and study the influence of the conditions under which the reactions take place upon the final results.

Modern Coal-Treating Plant. R. Wüster. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Sept. 18, pp. 1105–1110). Wet and dry methods of preparing coal as employed in Germany are described, and the difference between the plants and products briefly outlined. Auxiliary plant is dealt with, and important problems in coal treatment are discussed.

The Status of Bituminous Coal Cleaning. P. Lameck and M. Nierhaus. (Stahl und Eisen, 1937, vol. 57, Sept. 23, pp. 1041–1048; Sept. 30, pp. 1074–1079). The authors discuss the necessity of coal-cleaning processes, and the use of cleaned coal. Briquetting, coking and the recovery of by-products from the coking process are dealt with, including the desulphurising of coke-oven gas. Low-temperature carbonisation and the use of pulverised fuel for internal combustion engines, subterranean gasification, and various methods of producing liquid fuels from coal are described in detail.

Researches on the Increased Production of Benzol in the Overhead-Flue Oven. I and II. W. Demann and W. Brösse. (Technische Mitteilungen Krupp, 1936, vol. 4, Sept., pp. 150–152; 1937, vol. 5, Sept., pp. 176–197). After a preliminary review of the literature, the authors describe experimental condensing plant attached to a coke-oven in order to study methods of increasing the benzol yield. The crude coke-oven gases were analysed to determine their benzol content and the composition of the gas.

The Electrical Gas-Cleaning Plant at the East Moors (Cardiff) Steelworks. K. Guthmann. (Stahl und Eisen, 1937, vol. 57, Aug. 19, pp. 922–924). The author describes in detail the two-stage Lodge-Cottrell electrostatic cleaning equipment at the East Moors works of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.

The Production of Oils from Coal. C. P. Warden. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 38, July, pp. 1–21). The author examines in some detail the main features of various processes for extracting oil from coal; the chemistry of the processes is discussed. The prospects of an oil-from-coal industry in South Africa are considered.

PRODUCTION OF IRON

(Continued from p. 219 A)

The Schwarzenberg Blowing Machine, A Monument of Technical Culture. (Giesserei, 1937, vol. 24, Aug. 13, pp. 422–424). An historical account is given of a blowing engine constructed for use in an ironworks in 1830. Structure details are described.

Blast-Furnace Practice in France. F. Clerf. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 811 : Metals Technology, 1937, vol. 4, Aug., No. 5). The author describes blast-furnace practice in France, using minette ore for the production of basic Bessemer pig-iron. The design of the blast-furnaces in operation in Caen, Denain, Lorraine and Luxemburg are shown, and tables are included which give typical blast-furnace burdens, their analyses, and other operating data.

The Utilisation of Scoria from the Early Forges of la Montagne Noire (Languedoc). G. Vié. (Génie Civil, 1937, vol. 111, Sept. 25, pp. 273–274). The author examines the history and distribution of the scoria dumps on the supposed sites of prehistoric and pre-Roman forges in France. The quantities of scoria available are estimated, some analyses given (45% of iron with about 2 g. of gold and 12 g. of silver per ton, are present in some cases), and possible means of utilising the dumps as a source of iron are considered.

New Aspects of Siderurgy. A. G. Lefèbvre. (Revue Technique Luxembourgeoise, 1937, vol. 29, May–June, pp. 60–68; July–Aug., pp. 82–91). The author reviews the present position of the iron and steel industry in European countries—chiefly England and Germany—and examines and discusses general trends. The significance of these trends to the non-producing countries is considered.

Bases for the Development of a Costing System for the Iron Industry. C. E. Schulz. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 101–112). The author outlines the reasons for and aims of a uniform costing system, and discusses the essentials of such a system. The effects of external factors on the organisation are dealt with, and its application to the various branches of the industry are treated in detail.

FOUNDRY PRACTICE

(Continued from pp. 220 A–221 A)

The Scrap Price, Spout Iron Cost Problem. W. A. Phair. (Iron Age, 1937, vol. 140, Aug. 5, pp. 39–41). A practical examination is made of the recent trend towards high scrap percentages in cupola mixtures, and the effect of the present cost of raw materials on the costs of such mixtures is discussed.

Cast Irons Used for Various Types of Castings. A. L. Norbury. (Transactions of the Liverpool Engineering Society, 1937, vol. 58, pp. 62–73). The author discusses the compositions of commonly-used grey irons and the methods of producing such irons. The effects of variations in composition on the chief physical and mechanical properties of the casting are also dealt with.

Short Cycle Malleable Annealing Furnaces. C. H. Martin. (National Conference on Industrial Gas Sales, Chicago, 1937: Industrial Heating, 1937, vol. 4, Aug., pp. 632–634). A description is given of the gas-fired radiant-tube malleable annealing furnace for working on the short-cycle process (14 hr.) installed by the McCormick Malleable Foundry Co., Chicago. Constructional and operating data are discussed.

A New Moulding and Sand-Preparing Method. M. Olivo. (International Foundry Congress, Paris, 1937: Foundry Trade Journal, 1937, vol. 57, Aug. 26, pp. 159–161, 166). The author considers the advantages to be expected from vertical casting as opposed to casting on the slope, and describes a suitable layout for a vertical casting plant. A detailed description is presented of every phase of the working cycle.

Portland Cement as a Binder for Foundry Molding Sand. C. A. Menzel. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 200–216). Laboratory studies and the results of experiments carried out in foundries indicate that portland cement can be satisfactorily employed as a binder in foundry moulding sand. For facing, clean, well-graded silica sand with 10% of portland cement and 4·5% by weight (of the dry materials) of water should be used. Mixing and ramming are discussed in some detail.

Make Large and Small Castings. P. Dwyer. (Foundry, 1937, vol. 65, July, pp. 22–24, 63). An account is given of the pattern stores and production range of Sessions Foundry, near Bristol, Connecticut.

The Application of the Pneumatic Micrometer to the Control of Castings. L. Wattebot and A. Brizon. (International Foundry Congress, Paris, 1937: Foundry Trade Journal, 1937, vol. 57, Aug. 26, pp. 155–156). The authors describe Mennesson's pneumatic micrometer and show how its use has been extended to cover the examination and control of castings, for detecting porosity, &c.

PRODUCTION OF STEEL

(Continued from p. 222 A)

Works of Dorman, Long and Company Limited. (Iron and Coal Trades Review, 1937, vol. 135, July 16, pp. 100–101; July 23, pp. 141–144; July 30, pp. 173–177; Aug. 6, pp. 217–221; Aug. 13, pp. 253–256; Aug. 20, pp. 285–292; Aug. 27, pp. 323–329). An account of the various works attached to the Company is given, preceded by a brief historical review of the undertaking.

Statistical Researches on the Metallurgy of the Basic Bessemer Process During the Converter Run. T. Lütgen. (Stahl und Eisen, 1937, vol. 57, Sept. 9, pp. 993–999). After a brief review of the literature on the subject, the author considers the relationship of the duration of the blow to the converter wear and to individual heats. The weight of charge handled during a complete run and individual heats are dealt with, and the relationship between pig analysis, temperature, converter wear and blowing time is examined. The consumption of lime, scrap and ferro-manganese during a run is considered, and the analyses of the steel produced are discussed in relation to the blowing time and the converter wear. The manganese and phosphorus contents of the test-pieces and the burning away of the former element are dealt with, together with the manganese content of the bath and the iron content of the slag. The influence of the silica content of the slag and the effect of the duration of the blow on the iron content of the slag are studied, and the yield is discussed in relation to the converter wear and the blowing time. The pouring temperature under different conditions is studied, and the influence of the standing time on the analysis of the melt is noted.

Study of the Manufacture of Steel in the Acid Open-Hearth Furnace. H. Malcor. (Revue de Métallurgie, Mémoires, 1937, vol. 34, July, pp. 411–422).—Having described the acid open-hearth process in general terms, the author next considers in detail the different stages of the process as exhibited in practice, and the chemistry of the reactions which occur in relation to the charge and the analysis of the final product. Acid and basic open-hearth steels are compared and the superiority of the former is commented upon.

VIT Iron and its Production. P. S. Rogosin. (Metallurgist (Russia), 1936, No. 12, pp. 15–25). VIT iron (so called after V. I. Tyznov) is a commercially pure iron which has been produced since 1926 by the Molotov Machine Constructional Works. It is prepared by the basic open-hearth process, from 30–33% of pig iron and 70–67% of scrap steel, with the addition of 9–10% of limestone and of a quantity of iron ore, depending on the desired carbon content. The burning-out of the carbon takes 2½–5 hr.;

FOUNDRY PRACTICE

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PRODUCTION OF STEEL

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manganese is removed by repeatedly replacing the slags enriched in MnO by fresh ones. No deoxidising agent is used before tapping; the product contains therefore much oxygen and non-metallic inclusions. The rolled product has the following properties: (*a*) Rolled above 1000°; elastic limit, 21 kg. per sq. mm.; tensile strength, 35 kg. per sq. mm.; elongation, 27–36%; reduction of area, 66–72%. (*b*) Rolled below the brittle range (850° C.): elastic limit, 24–25 kg. per sq. mm.; tensile strength, 37 kg. per sq. mm.; elongation, 23–35%; reduction of area, 71–74%. The rolled metal is plastic and can be drawn without annealing; it is only slowly hardened by cold-working. The following thermal treatment gives good results both with hot-rolled and with cold-drawn metal: Heating to 1050° for 2 hr., cooling to 650° in the furnace, holding at 650°, and slow cooling. The magnetic properties are: Remanence, 6400–8400 gauss; coercive force, 18 oerstedts, unchanged by nitrogen up to 0·35%, but reduced to 6 oerstedts by 0·5% of nitrogen. (In Russian).

The Ingot Phase of Steel Production. E. Gathmann. (Blast Furnace and Steel Plant, 1936, vol. 24, Dec., pp. 1067–1068; 1937, vol. 25, Jan., pp. 81–83; Feb., pp. 202–204, 213; Mar., pp. 289–291; Apr., pp. 416–418; May, pp. 504–505; June, pp. 622–623; July, pp. 730–731; Sept., pp. 1004, 1017). The author discusses the solidification and segregation of ingots. The essentials of ingot-mould design, the uses and effect of washes are dealt with, together with the effects of ferrostatic pressure on the life of the mould and the stool.

FORGING, STAMPING AND DRAWING

(Continued from p. 224 A)

Packard Accuracy begins in the Forge Shop. F. J. Oliver. (Iron Age, 1937, vol. 140, Sept. 9, pp. 40–44). Die material is referred to of the following composition: Carbon 0·5–0·6%, nickel 1·25–1·75%, chromium 0·50–0·75%, molybdenum 0·10–0·30%, vanadium 0·30% (max.). The dies are used for forging and coining and have a hardness value of 52–55 Shore. The use of cast alloy-steel die blocks is noted.

Time Studies in Forging Shops and Their Commercial Utilisation. G. Schmidt. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Sept., pp. 157–162). The author describes the technique of making time studies of typical forging operations. The Peiseler " Diagnostiker " is suggested as a suitable type of chronograph to use for the purpose. The methods of calculating various values are dealt with.

Tests on the Evaluation of the Forgeability of Metals and Alloys. A. Portevin and J. de Lacombe. (Annales de l'Académie des Sciences Techniques à Varsovie, 1935, vol. 2, pp. 167–198). The authors describe the technique of testing in torsion, compression, bending, tension, impact compression, and by impact. The interpretation of each test is detailed. Experimental results are presented for several forgeable carbon steels, the analysis of one being given, namely, carbon 0·80%, silicon 0·320%, manganese 0·310%, sulphur 0·020%, phosphorus 0·018%, and copper 0·140%. Of other steels examined, two contain 40% of nickel and one contains 12·35% of chromium together with 13·16% of nickel, 2·25% of tungsten and 1·31% and 0·40% of silicon and carbon respectively.

Recent Progress in Cold Heading Machinery. R. H. Jones. (Wire and Wire Products, 1937, vol. 12, Sept., pp. 479–483, 501). A review is presented of the improvements in cold-heading machine design and construction which have occurred during the past few years.

Press Innovations at Grand Rapids Stamping Plant. (Iron Age, 1937, vol. 140, Aug. 12, pp. 50–53). A description is given of heavy presses installed by Fisher Body Co., at its Grand Rapids Stamping Division. The layout, construction and operating features of the equipment are discussed in some detail.

ROLLING-MILL PRACTICE

(Continued from p. 225 A)

Resolutions Adopted by the Conference on the Design of Rolls for the Rolling of Special Steels. (Katshestvennaia Stal, 1936, No. 10, pp. 7–11). A report is given of the resolutions adopted by a conference held on 20 to 24 July, 1936, after hearing the following reports:

RUDBACH : Design of rolls for special steels.

SHILKOV : Geometrical construction of passes for rolling special steels.

BOICHENKO : Roll designs used abroad.

ROTHENBERG : Experience gained in the use of circle–oval and oval–oval systems.

I. K. AUZIFEROV : Roll economy.

(In Russian).

New Half-Open Roll-Neck-Seating Construction. K. Suresch. (Stahl und Eisen, 1937, vol. 57, Sept. 9, pp. 1004–1005). A description is given of the plastic bearings on the rolling-mills of the Burbacher Hütte. To avoid " hammering " and to obtain floating support, a new type of construction involving half-open bearings was evolved. The plastic shell which forms the bearing is built up of strips supported in a metal housing.

Copper-Lead Bearing Metals Favored for Severe Service. F. G. Jenkins. (Metal Progress, 1937, vol. 32, Aug., pp. 145–149). Reference is made to the casting of copper-lead alloys on to steel strip, which is subsequently cut up and bent to shape for bearings.

The Technical Mechanical Requirements of Lubricating Oils and Greases. E. Heidebroek. (Angewandte Chemie, 1937, vol. 50, Sept. 11, pp. 743–747). The author emphasises the importance of differentiating between the stability factor (resistance to ageing, &c.), and the load-carrying-capacity factor, in the examination of lubricating materials. The significance of correct lubricating technique is noted, and the nature and particular applications of various types of lubricant are discussed.

The Determination of Coefficients of Friction by Means of the Vollet Machine, and the Influence of Colloidal Graphite in Lubricating Oils. (Génie Civil, 1937, vol. 111, Sept. 25, pp. 271–272). A description is given of Vollet's machine for determining coefficients of friction, and of the method of calculating such values from the data obtained. Curves are given for graphitised and non-graphitised oils.

How Drag Generators Function in Holding Tension in Strip Mills. R. S. Sage. (Steel, 1937, vol. 101, Sept. 13, pp. 48–51). The author describes briefly the evaluation and application of the so-called drag-generator which may now attain capacities up to

70 Kw. Such a generator is usually a D.C. adjustable-speed machine, and when in operation returns power to assist the main generator in driving the various motors in the rolling-mill.

Developments in the Construction of Cold-Rolling Mills. J. Maas. (Stahl und Eisen, 1937, vol. 57, Sept. 30, pp. 1080–1082). The author describes recent developments in cold-rolling plant, including four- and six-high mills, reversing mills and coiling mechanism.

Shears for the Hot Cutting of Steel. V. A. Erachtin. (Katshestvennaia Stal, 1937, No. 1, pp. 54–55). Measurements of the temperature of steel-cutting shears by means of a thermocouple gave readings of about 500° C.; the steel used for making the shears must therefore retain its hardness up to 600° C. A steel with 2% of chromium and 8% of tungsten was found to satisfy these requirements better than a steel with 1·2% of chromium and 2·5% of tungsten. Instructions are given for the thermal treatment of the shears. (In Russian).

Wheel and Roller Conveyors and Ball Transfers Installed in Steel Plant. (Steel, 1937, vol. 101, Aug. 16, pp. 57–58). A description is given of handling plant for sheet and plate at the Granite City Steel Co., Granite City, Illinois.

HEAT TREATMENT

(Continued from pp. 227 A–228 A)

Diffusion in Solid Metals. A. I. Krynitsky. (Metals and Alloys, 1937, vol. 8, May, pp. 138–144; June, pp. 173–179). A correlated abstract of the work of various investigators on the diffusion phenomena in solid metals.

A Theory of Diffusion in Solids. J. E. Dorn and O. E. Harder. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 836: Metals Technology, 1937, vol. 4, Sept., No. 6). The authors outline the nucleus of a theory of diffusion, which shows some of the relationships between the energy of loosening an atom and the melting point, diffusibility and solubility. Equations for interstitial and substitutional diffusion are developed, and examples are indicated of the applications of the theory.

Diffusion of Carbon from Steel into Iron. L. C. Grimshaw. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 843; Metals Technology, 1937, vol. 4, Sept., No. 6). The author describes experiments in which electrolytic iron was deposited upon six different steels, the diffusion of carbon from these steels into the electrolytic iron being observed and measured. It was found that the rate of carbon diffusion from steel into iron increases with temperature. However, this increase in the rate of diffusion is not a function of temperature alone, but is most influenced by the phase of the steel and of the iron at any temperature. As the temperature is raised to the point where the steel is in the γ phase while the iron remains in the α phase, carbon diffuses slowly into the α iron, and when saturated with carbon the α iron changes to γ iron. The diffusion into α iron is greatly influenced by the concentration gradient. At higher temperatures, where both the steel and the iron are in the γ phase, diffusion is much faster, and increases in rate as the temperature is raised, although it is very little influenced by the carbon-concentration gradient. Alloys in the steel influence the rate of carbon diffusion from steel into iron. The addition of small amounts of alloying elements that do not combine with all of the carbon to form stable carbides increases the rate of carbon diffusion. When the carbon is in the form of stable carbides in the steel, time is required, even at temperatures where the iron is in the γ phase, for the carbides to diffuse into the γ iron, and there break down and allow the carbon to go into solution and diffuse rapidly.

Case Hardening by Direct Transformation of Austenite. B. R. Queneau and R. L. Dowdell. (Transactions of the American Society for Metals, 1937, vol. 25, Sept., pp. 904–922). The authors describe a practical method for the hardening of case-carburised steels by the delayed transformation of the austenite at temperatures

below 600° F. The method is said to produce stronger and tougher cases with a hardness of about 60 Rockwell C.

Diagnosis of Metal Trouble in Industry III.—Carburizing. J. L. Burns and V. Brown. (Metal Progress, 1937, vol. 32, Aug., pp. 151–156). The authors deal with faults in carburised work, such as soft spots, excessively thick or thin cases, grain growth, use of too high or too low a carburising temperature, and wrong quenching temperatures.

Hydrogen Decarburisation of Pure Iron-Carbon Alloys and Alloyed Steels. W. Baukloh and W. V. Kronenfels. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Sept., pp. 145–156). The dependence of decarburisation by hydrogen on temperature and carbon content was studied on pure iron-carbon alloys containing up to 1·7% of carbon. Grey and chilled iron-carbon alloys containing above 1·7% carbon were also examined, and it was shown that the form of the carbon exercised a decisive influence on the process of decarburisation by hydrogen; although intrinsically more easily affected by hydrogen, the cementite suffered less decarburisation than those materials containing graphite, owing to the impermeable nature of its structure. Experiments on steels containing silicon, manganese, nickel, chromium, tungsten, titanium and aluminium showed that even in small quantities these additions exert a considerable effect on the decarburisation process. According to whether they dissolve in the iron or form stable carbides they affect the diffusion velocities of hydrogen and carbon; it is not possible to classify the alloy additions from this standpoint, however, as their influence varies, in addition, with the carbon content.

Voids in Graphitic Steels. M. L. Samuels. (Metal Progress, 1937, vol. 32, Aug., pp. 167–168). The author questions the statement made in an article by Bonte and Fleischmann (*see* p. 90 A) that graphite is absorbed during the heat treatment of graphitic steels, leaving voids to act as oil-pockets. The physical processes occurring during the heat treatment of such steels are discussed. Fleischmann re-affirms his statement, however, in a reply to Samuels.

The Development of Today's Scale Spring. J. W. Rockefeller. (Wire and Wire Products, 1937, vol. 12, Sept., pp. 475–477). Reference is made to the heat treatment and Rockwell hardness-testing of a 0·50–0·53% carbon, 0·68% manganese steel spring.

An Experimental Study of Gases for Controlled Atmospheres. E. E. Slowter and B. W. Gonser. (Metals and Alloys, 1937, vol. 8, June, pp. 159–168; July, pp. 195–205). The authors describe various types of gases for controlled atmospheres, including partly burned gases, and discuss gas reactions in connection with their use. The experimental work comprises a study of the behaviour of typical commercial protective atmospheres on non-alloy steels with 0·07 to 1·04% of carbon. Analyses are given for the steels

tested, and the composition and source of the protective gases are stated. The effects of heating the steel in the various atmospheres are presented graphically in relation to time and temperature.

The Use of a Protective Atmosphere in the Annealing of Steel. R. Buchkremer. (Metallwirtschaft, 1937, vol. 16, Sept. 24, pp. 992–996). The author discusses the decarburisation process which occurs on annealing steel, and considers the influence of the duration of heating and of the composition of the steel and the atmosphere upon the course of the reactions which take place. Various gases suitable for the production of protective atmospheres are then considered.

Bathtubs Annealed in Huge Atmosphere Furnace. E. Stephenson. (Industrial Heating, 1937, vol. 4, Aug., pp. 636–638, 641). A description is given of a large radiant-tube-heated annealing furnace of the conveyor type, fired with propane (2500 B.Th.U.), installed by the Briggs Manufacturing Co., Detroit, Michigan.

Influence of Isothermal Heat Treatment on the Mechanical Properties of Steel. V. D. Sadovsky. (Katshestvennaia Stal, 1936, No. 10, pp. 42–44). The author describes the results obtained in the Slatoust Works with the isothermal hardening and stepped hardening of chromium-nickel steel, as well as those obtained by isothermal tempering. The differences in mechanical properties of the steels hardened isothermally or in steps from those hardened in the usual way are based on differences in the residual content of undissociated austenite. They therefore nearly disappear after the ordinary hardened steel has been subjected to tempering at high temperature, leading to a structure resembling sorbite. The method of isothermal tempering has given uniformly good results in Slatoust when applied to both high-speed and chromium-nickel structural steel. (In Russian).

Mechanism of Structural Changes in the Tempering of High-Speed Steel. A. P. Gulajev. (Metallurgist (Russia), 1936, No. 12, pp. 73–79). The author used the dilatometric and the magnetometric methods to investigate the kinetics of the tempering of high-speed steel (carbon 0·75%, tungsten 18·3%, chromium 4·16%, vanadium 0·50%). The influence of the temperature of quenching, of the temperature and duration of tempering, and of the velocity of cooling was determined, as well as the effect of cooling in steps and of repeated tempering. The following are his general conclusions. Quenched high-speed steel consists of martensite, residual austenite and free carbides. The quantities of carbides and of austenite decrease and the amount of martensite increases with increasing temperature of hardening and duration of heating before quenching. The tempering serves to decompose the residual austenite. During heating to the tempering temperature, only the decomposition of the solid solution of carbides in the austenite occurs, but no transformation of the austenite itself. This last process takes place during the cooling after tempering. The higher the temperature and the

longer the duration of the tempering, the greater is the quantity of carbides set free, and the more effective is the austenite-martensite transformation in the following cooling process. The transformation begins, for instance, at 120° C. after 10 min. tempering at 600° (steel quenched from 1300°), at 195° after 1 hr. tempering, and at 280° after 3 hr. Slow cooling is not necessary for complete transformation. On the contrary, quick cooling gives greater stresses, and thus favours the austenite-martensite transformation. To achieve complete decomposition of the austenite, it is possible to use either one single prolonged tempering, or a series of shorter temperings. In the first case the martensite contains less carbides than in the second; the properties of the steels treated by these two methods are therefore different. All these results apply to steel quenched from 1100° or higher. At lower quenching temperatures (850–900° C.) the austenite contains but little dissolved carbides; on tempering it there is a transformation of the residual austenite and of the martensite into troostite, which occurs during the heating, in the interval 100–350° C. (In Russian).

Isothermal Annealing of Hot Ingots and Forgings. I. P. Lipilin. (Katshestvennaia Stal, 1936, vol. 10, pp. 12–22). Isothermal annealing is compared with the ordinary slow-cooling process for six steels: (1–3) Tool steels (chromium-tungsten-vanadium, chromium-tungsten-manganese), (4) Ball-bearing steel (chromium) and (5) and (6) two structural steels (chromium-nickel and chromium-tungsten-nickel). Five series of experiments were made: (*a*) Slow cooling in the furnace of small discs cut from rolled bars, (*b*) isothermal annealing of the same discs in a lead bath, (*c*) isothermal annealing of samples cut from ingots and large forgings, (*d*) isothermal annealing of whole hot ingots and (*e*) isothermal annealing of whole hot forgings. (*a*) Steels (1) to (4) are softened already at 750–650° C.; it is therefore an unnecessary loss of time to continue slow cooling below these points. Steels (5) and (6) are softened first below 400° C.; they are better softened by isothermal hardening and high-temperature annealing. (*b*) The velocity of softening has a maximum about 100° below the critical point. Steels (1) to (4) can be softened isothermally in 15 to 30 min., (5) requires about 1 hr., and (6) cannot be softened by this method at all. Best results are obtained with steels (1) to (4) at temperatures somewhat above that of the maximum velocity. (*c*) With steels (1) and (2), the transformation of austenite goes more slowly in forgings than in rolled bars, and still more slowly in castings; hot mechanical treatment facilitates the breakdown by crushing the carbides and producing dissociation centres. With hypereutectoid steels (3) and (4) differences in the dissociation velocity of ingots, forgings and rolled bars are much smaller, and with the eutectoid steel (5) ingots and forgings are transformed more quickly than bars. (*d*) Ingots made of steels (1) to (4) were successfully annealed by placing them when at a temperature of 1000–800° C.

in a furnace heated to 500–600° C., and heating first to a temperature of $Ac_1 - 100°$, and then to $Ac_1 - 50°$. Steel (5) was first homogenised at 1150°, isothermally hardened at 300° and annealed at 650°. A great economy in time is obtained by the isothermal annealing of steels (1) to (4). With structural steel (5), isothermal annealing prevents the occurrence of defects which may arise owing to the martensite transformation. (*e*) Equally good results were obtained by the isothermal annealing of forgings of all the six steels investigated. (In Russian).

Heat Treatment of Deep Drawn Sheet Steel. A. M. Gontsharov. (Katshestvennaia Stal, 1937, No. 1, pp. 23–27). Experiments show that the most important factors determining the plastic properties of sheet steel are the grain size and the distribution of the cementite. The best grain size is about 2000 per sq. mm.; it is obtained by annealing at 900° C. and cooling at a rate of 2–3° per min. (In Russian).

Differential Hardening by Induction. M. A. Tran and W. E. Benninghoff. (Transactions of the American Society for Metals, 1937, vol. 25, Sept., pp. 935–952). The author describes the hardening of automobile crankshafts by means of a high-frequency current of 2000 cycles. The resulting surface structure of high hardness and its gradual blending into the core structure are described, and suggested changes and modifications in crankshaft production methods are outlined.

WELDING AND CUTTING

(Continued from pp. 229 A–230 A)

Some Factors to be Considered in the Choice of a Welding Process. L. J. Larson. (Welding Journal, 1937, vol. 16, Sept., pp. 40–45). The author discusses the bases of the choice of a suitable welding method for various types of work. Hammer welding, electric welding processes of various kinds, flash welding, fusion welding (including thermit welds), gas welding, atomic hydrogen and metallic arc welding are considered.

What Happens in the Welding Arc. S. C. Osborne. (Welding Journal, 1937, vol. 16, June, pp. 11–15). The author discusses briefly the characteristics of the electric arc and their significance in welding technique.

Leftward and Rightward Gas-Welding Techniques. A. Hilpert. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Aug. 21, pp. 995–997). The author examines the leftward and rightward welding techniques and concludes that the rightward process is better for thick sheets, and the leftward more suitable for sheet up to 4 mm. in thickness and for non-ferrous metals.

Welding Symbols and Instructions for their Use. (Welding Journal, 1937, vol. 16, June, Supplement, pp. 1–11). A complete list of symbols drawn up by the American Welding Society for use in connection with every phase of welding practice is presented. The list has been developed from symbols used in both America and other countries, and supersedes the revised list published in bulletin form in Feb. 1935. It has been recommended to the American Standards Association for adoption as a standard.

Temperature Distribution During Welding. A Review of the Literature to January 1, 1937. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Sept., Supplement, pp. 4–10). In gas welds maximum temperatures of 1000° C. are reached at the centre of 0·39 in. thick plate 0·75 in. from the weld; the temperature drops to 300° C. about 3 in. from the weld. In arc welds a temperature of 1000° C. obtains only at distances less than 0·25 in. from the centre of the weld. The temperature gradient is steeper, the hot zone narrower, and the cooling from any given temperature more rapid in an arc than a gas weld. Conclusions are drawn as to stress gradients due to thermal reactions.

Welding Malleable Cast Iron. A Review of the Literature to December 1, 1936. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, June, Supplement, pp. 10–14). The authors discuss the metallurgy and physical properties of whiteheart and blackheart malleable irons, and summarise the recommended welding techniques for both.

Fusion Welding Wrought Iron. A Review of the Literature to January 1, 1937. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Sept., Supplement, pp. 11–22). The structure of wrought iron and its properties in general differ sufficiently from those of mild steel to create definite differences in fusion welding characteristics. The authors review these differences in connection with the mechanical and physical properties of the material and from the standpoint of fusion welding technique.

Welding Special Ferrous Alloy Castings. A Review of the Literature to November 1, 1936. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, June, Supplement, pp. 5–10). The authors summarise the technique of welding 14% manganese steel, high-chromium and nickel-chromium alloy steel castings, high-silicon iron, and Nicrosilal and Ni-Resist. Tabular data on mechanical properties are included.

The Welding of Stainless Steel. V. W. Whitmer. (Welding Journal, 1937, vol. 16, Sept., pp. 8–19). After describing briefly the composition of some austenitic stainless steels the author details the gas and arc welding, spot and projection welding, and seam, flash and atomic hydrogen welding techniques required for successfully jointing these materials. Brazing and silver soldering are also dealt with.

The Welding of Stainless Nickel-Free Chromium Steels. W. Tofaute. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Sept. 18, pp. 1117–1122). The nickel-free stainless steels are grouped as follows: Martensitic steels with chromium 12–18% and carbon 0·15–0·45%; the semi-ferritic low-carbon chromium steels with chromium 12–18%; the low-carbon ferritic steels with 19–30% of chromium, the ferritic-austenitic and wholly austenitic manganese-chromium steels, with a high manganese content. Welding tests were carried out on the second and third types, to which additions of silicon, molybdenum, titanium, tantalum and niobium had been made. Welding was carried out in various ways and tests were conducted on the unheat-treated weld to determine completely its mechanical and corrosion-resisting properties. Gas and electric welding with filler-rods of the same composition as the work gave only mediocre mechanical results; arc welding with a coated 18/8 electrode yielded a better elongation and bend, but chromium steel with chromium 18–30% and additions of titanium, tantalum or niobium gave results of really practical value insofar as the total carbon content was fixed by the addition elements. Plant fabricated in the light of these researches is already in the course of construction.

Welding High-Tensile Boiler Steels. H. Aysslinger. (Wärme, 1937, vol. 60, Apr. 3, pp. 220–225: Welding Journal, 1937, vol. 16, June, Supplement, pp. 15–16). An account is presented, with tabulated data, of tensile, roller-bend, face bend, notch impact,

quench-impact, and strain impact tests on plain carbon steels of approximately 0·2% carbon content.

Some Modern Boilers in the United States. C. M. Stein. (Mémoires de la Société des Ingénieurs Civils de France, 1937, vol. 90, Jan.–Feb., pp. 90–129). The employment of arc-welded components of low-carbon molybdenum steel in high-pressure steam plant is referred to.

Fabricating Houlet Superheater Tubes. (Soudeur-Coupeur, 1937, vol. 16, Aug.-Sept., pp. 1–3). An account is presented of the technique of welding chromium-copper steel (Chromesco) superheater tubes.

200-In. Telescope, World's Largest, has Mounting of Welded Steel. G. H. Froebel. (Metal Progress, 1937, vol. 32, Aug. pp. 132–137). A description is given of the fabrication of the mounting for the Mount Palomar Telescope. Components were largely built up by gas welding, but during erection, arc welding, employing heavily coated electrodes, was used. Structural features are also dealt with.

Absorption of Nitrogen During the Welding of Steel. B. B. Gezov. (Katshestvennaia Stal, 1936, No. 10, pp. 45–46). The author estimated the concentration of nitrogen in the joints obtained by welding Armco iron (*a*) with the oxy-acetylene flame and (*b*) with the electric arc. In case (*a*) the concentration of nitrogen was about 0·02% in an atmosphere of air hydrogen or pure nitrogen and only higher (0·08%) in ammonia gas. In case (*b*) the joint contained up to 0·2% of nitrogen, depending on the kind of current used (A.C. gave a higher percentage), the length of the arc, the kind of electrodes and the atmosphere in which the arc burned. (In Russian).

Behaviour of Welded Girders under Repeated Stress. W. Stein. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Sept. 18, pp. 1126–1127). The author pays special attention to the effect of welding stresses and considers in particular their effect on the fatigue strength of the structure.

The Effect of Total Carbon and Manganese on the Mechanical Properties and Structure of Welded Joints in Plain Low-Carbon Steel. A Review of the Literature to January 1, 1937. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Sept., Supplement, pp. 23–32). Welds in steels containing high manganese and carbon have higher tensile strengths than those in steels containing smaller amounts of these elements. The maximum hardness increases with increasing carbon and manganese and with increasing welding speed. There is apparently no tendency to lower ductility or impact values with variation in carbon and manganese.

Strain Measurements in Welded Joints. J. L. Banville and H. A. Storrs. (Welding Journal, 1937, vol. 16, June, Supplement, pp. 1–4). The authors describe the results of experiments on the development of a method for measuring the ductility of the metal in a weld

while under a series of tensile stresses in order to determine the entire elastic curve of the metal.

Introduction to the Study of Welds. E. Warnant and D. Rosenthal. (Laboratoire de Connaissance des Matériaux de l'Université Libre de Bruxelles, 1937, Bulletin No. 1). The authors consider first the metallurgy of the weld, and examine it from both the physical and chemical standpoints. The second part of the booklet deals with the application of welding to structural work of various types, and embraces discussion on the development of designs, the technique of fabrication and the mechanical properties of welded joints.

Economy in the Use of Tin in Solders. (Metallwirtschaft, 1937, vol. 16, Aug. 20, p. 962). It is noted that attempts to improve the mechanical properties of 10–15% tin solders by the addition of heavy metals of high melting point result in difficult manipulation and poor adhesion on tinplate and zinc-coated sheet.

PROPERTIES AND TESTS

(Continued from pp. 236 A–245 A)

The Development of a Machine for High Speed Testing of Materials. R. J. Lean and H. Quinney. (Proceedings of the Institution of Mechanical Engineers, 1937, vol. 135, pp. 467–483). The authors give an account of a research into the effect on metals of different speeds of fracture, using a specially designed high-speed testing machine which is described in detail. The experiments were conducted both in this machine and in a 5-ton variable-speed autographic tensile machine, on five steels, the rate of loading being varied for each. With the high-speed machine toughness, ductility, time to produce fracture, and the stress-strain curve were obtained. The results of these combined tests, given in tables and graphs, show that there is a marked increase in stress due to higher speed of testing, and also that the work required to cause fracture increases with the speed. For mild steel the stress at the initial yield point was found to be in excess of that at the maximum point; when the speed of testing was increased the ductility did not appear to suffer.

Factors Relating the Impact Strength of Metals with Their Service. (Metal Progress, 1937, vol. 32, Aug., pp. 138–141). The significance of the impact test as a measure of suitability for service is discussed and the practical implications of the impact value examined in relation to temperature, loading velocity, nature of the notch, and the mass of metal under consideration.

Influence of Tempering at Low Temperatures on the Mechanical Properties of Hardened Steel. B. E. Scheinin. (Katshestvennaia Stal, 1937, No. 1, pp. 15–20). The author discusses the data of different investigators concerning the dependence of the impact toughness of hardened carbon steels on the temperature of tempering. He then describes his own experiments on the same change as observed in two different chromium steels. The maximum impact toughness is obtained by tempering at 150–175° C. The author concludes that changes in toughness caused by tempering are due to structural transformations (breakdown of residual austenite, liberation of carbon from supersaturated martensite, coagulation of carbides) and not simply to the release of internal stresses. (In Russian).

Residual Tangential Stresses in Hollow Steel Cylinders after a Cold Mechanical Treatment from Inside. E. S. Tovpenez and P. S. Sacharov. (Metallurgist (Russia), 1936, No. 12, pp. 36–42). The authors have investigated the stresses remaining in steel tubes after drawing a steel sphere through the interior. These stresses can be removed by annealing at 400° C. or higher, combined with a removal of the surface layer, *e.g.*, by a reduction of the external diameter from 22 to 16 mm. (In Russian).

Progress in the Optical Determination of Stress. (Forschung auf dem Gebiete des Ingenieurwesens, 1936, vol. 7, pp. 240–248 : Stahl und Eisen, 1937, vol. 57, Sept. 9. pp. 1005–1006). An account is given of the work of G. Oppel on stress determinations by means of models constructed of synthetic resins. Oppel's discovery that the optical behaviour of the resin (and apparently of glass) depends on the elongation caused by stress and not on the stress itself is described and its application is dealt with in some detail, particularly in connection with the determination of internal stress.

A New Type of Rotary Fatigue Testing Machine for Metals. M. Prot. (Revue de Métallurgie, Mémoires, 1937, vol. 34, July, pp. 440–442). An account is given of the rotary fatigue testing machine designed by Caquot for the simultaneous testing of a large number of small test-pieces; the latter are of a special shape.

On the Thermic Effects Associated with the Ageing Processes. J. Czochralski, R. Smoluchowski, and H. Calus. (Wiadomości Instytutu Metalurgji i Metaloznawstwa, Warsaw, 1937, vol. 4, No. 2, pp. 45–50). The ageing effect is considered to occur in two stages : first the diffusion of atoms of the dissolved metal to certain parts of the lattice of the solvent metal, and then the formation of molecules and finally of crystals of the precipitated phase. The use of the microcalorimeter is described, and it is shown that whilst valuable evidence of the processes which occur during ageing are obtained by means of this instrument, it is insufficient to enable general conclusions to be drawn. (In Polish).

Factors Influencing Wear of Valve Seats in Internal Combustion Engines. C. G. Williams. (Engineering, 1937, vol. 143, Mar. 26, pp. 357–358; Apr. 23, pp. 475–476). A summary of the data and conclusions which have been reached in the investigation of the wear of valve seats in internal combustion engines carried out by the Institution of Automobile Engineers, is given.

Wear of Metallic Surfaces. E. E. Le Van. (Metals and Alloys, 1937, vol. 8, July, pp. 206–209). After a discussion on the mechanism of wear, the author describes results obtained with Sawin's wear-testing apparatus and refers to improvements effected in the wear-resistance of certain metals used for tools and valves.

Influence of Cobalt, Chromium and Manganese on Iron-Nickel-Aluminium Alloys for Magnets. A. S. Saimovsky and P. I. Denissov. (Katshestvennaia Stal, 1936, No. 10. pp. 31–38). The authors have investigated the possibilities of improving the magnetic properties of Fe–Ni–Al alloys. An increase in residual induction and saturation is only possible by decreasing the concentration of nickel and aluminium, thus causing a substantial decrease in the coercive force. By compensating the decrease in concentration of nickel and aluminium by adding 5 to 10% of cobalt it is possible to retain a coercive force of 500 to 700 oersted, with residual induction up to 7000 to 8000 gauss. The alloy proposed contains 20 to 22% of nickel, 9 to 12% of aluminium and 5 to 10% of cobalt. The

above magnetic data were obtained with commercial castings, which have a magnetic energy 30 to 40% higher than that of the usual Fe–Ni–Al alloys. Comparison of the experimental results with Akulov's hysteresis theory showed that the coercive force of alloys cannot be predicted from a consideration of the natural anisotropy alone. (In Russian).

A Note on the Influence of Grain Size on Magnetic Hysteresis. G. C. Richer. (Iron and Steel Institute, Sept., 1937: this Journ. p. 323 P). Much investigational work has been done in recent years on the influence of grain size on magnetic hysteresis; and although most observers are in agreement that, other things being equal, the hysteresis loss decreases as the grain size increases, it has not hitherto been found possible to formulate a general expression of the mathematical relationship between crystal size and the magnitude of the hysteresis effect. In this note, the suggestion is advanced that the difficulty in correlating the grain-number N with the hysteresis loss associated with the grain-size effect arises from the fact that the quantity N is a purely arbitrary number, which can only give a satisfactory indication of the true characteristics of a given crystal structure under certain rather restricted conditions—conditions which are not usually satisfied by the types of specimen which are commonly submitted to metallographic and magnetic measurement. The fundamental physical conditions which govern the appearance and the magnitude of the grain-size hysteresis loss are discussed, and equations are formulated which appear to indicate that by approaching future investigation of this subject from a new angle there is a possibility that it will be easier to arrive at a more satisfactory correlation between the observed hysteresis loss and the pertinent magnitudes of the crystal structure under examination.

Special Steels with Anomalies in the Thermal Dilatation and in the Dependence of the Modulus of Elasticity on the Temperature. (Contribution to the Theory of Invar and Elinvar.) J. B. Friedman. (Katshestvennaia Stal, 1937, No. 1, pp. 47–54). The paper contains a discussion of the existing theories of the invar alloys and a new theory proposed by the author. He assumes that the presence of iron atoms in the γ-lattice of nickel causes internal stresses and a consequent swelling of the crystal. This "primary" mechanical dilatation causes a "secondary" swelling effect, due to magnetic forces (analagous to the well-known "mechanostriction" effect). The decrease in the magnetic swelling with increasing temperature and its disappearance at the Curie point counterbalance the normal thermal dilatation, and result in the volume remaining constant up to the Curie point. The mechanical swelling disappears only above the melting point (1425° C.), causing a further volume anomaly of invar (the specific volume decreases on fusion, and a further contraction takes place up to 1700° C.). It is thus not necessary to assume the existence of a compound Ni_2Fe to explain the pro-

perties of invar. The anomalies of the elastic modulus of elinvar are explained in the same way; it is shown that the relation of the dilatation coefficient to the temperature coefficient of the modulus of elasticity is the same (-4×10^{-2}) for a number of different alloys. The "magnetic" theory of invar predicts that no alloys of this kind can be prepared with a non-ferromagnetic base. (In Russian).

Effect of Silicon on Chromium-Molybdenum Steels for High-Temperature Service, with a Note on the Effect of Copper. N. D. Newell. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 835; Metals Technology, 1937, vol. 4, Sept., No. 6). The author presents some preliminary data on the effect of silicon on certain chromium-molybdenum steels at present in use in the oil-refining industry and includes a short statement on the influence of copper in steels intended for high-temperature service. Where oxidation resistance is of prime importance, improvement in this direction in chromium-molybdenum steels can be gained by the addition of silicon. The silicon should be limited to about 1·50% in steels containing from 2 to 5% of chromium. A higher silicon content results in a loss of impact strength and in a tendency to reduced ductility, and should be avoided where shock stresses are likely to be encountered when the metal is cold. The increased resistance to oxidation is gained at some sacrifice of high-temperature strength properties (both short-time and creep strength), and it is believed that further investigation will bear out the contention. A compromise must be made in using the silicon-containing alloys, and the choice of material will be dependent on whether maximum creep strength or maximum oxidation resistance is of paramount importance.

Alterations in the Structure and Properties of Heat-Resisting Chromium-Aluminium and Chromium-Silicon-Aluminium Steels due to Nitrogen Absorption. G. Bandel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Sept., pp. 139–144). Ferritic chromium steels and chromium-silicon steels heated to high temperatures in pure nitrogen or gases containing elementary nitrogen absorb nitrogen which forms nitrogen-austenite with the carbides and the groundmass. Excepting in the case of chromium-aluminium steels, the heat-resisting properties are not affected, but the aluminium-bearing steels lose aluminium, which is precipitated as a nitride, and with continued exposure nitrogen-austenite is formed in the matrix. The diffusion of aluminium to the surface to form alumina is in this way prevented and the heat resistance is in consequence diminished and locally increased oxidation may be favoured.

Internal Fissures Induced in Rails by Soaking in Hydrogen. H. F. Moore (Metal Progress, 1937, vol. 32, Aug., pp. 159–161). This article is based on the third progress report of investigations of fissures in rails sponsored by the American Railway Engineering Association (*see* Journ. I. and S.I., 1936, No. I, p. 103 A; 1937, No. I, p. 86 A). Descriptions are given of tests to demonstrate

the cause of shatter cracks, and results are presented showing the improvements effected by hardening the ends of the rails.

The Production of Flakes in Steel by Heating in Hydrogen. R. E. Cramer. (Transactions of the American Society for Metals, 1937, vol. 25, Sept., pp. 923–934). The author shows that flakes or small cracks were produced in steel (carbon 0·80%, manganese 0·80%), when heated at 1200° C. for 27 hr. in an atmosphere of hydrogen, followed by cooling in air. A different type of cracking resulted when a specimen was heated in hydrogen until the surface began to melt and then air-cooled. Specimens heated in hydrogen and quenched in water showed numerous small cracks. Although it has been demonstrated that hydrogen can cause flakes in steel during cooling, there is no proof that other causes, such as localised temperature gradients, cannot also produce flakes. No relation was found between the presence of flakes and the gas content of the steel after cooling. Further experiments are necessary to determine accurately the temperature at which flakes are formed.

The Problem of the Degassing and Refining of Metals and Alloys. H. Lepp. (Revue de Métallurgie, Mémoires, 1937, vol. 34, July, pp. 443–446). The mechanics of the solution of gases in metals are briefly discussed and the relatively powerful effects of certain gas-metal compounds on the mechanical properties of the metal noted. The solubility of hydrogen in iron is referred to. Means of degassing molten metals are discussed.

Influence of Tantalum on the Properties of Steel. N. Grechko and E. G. Perelman. (Metallurgist (Russia), 1936, No. 12, pp. 64–72). The addition of tantalum raises the transformation points Ac_1, Ac_3, Ar_1, Ar_3. The Ac–Ar interval is reduced. The velocity of the decomposition of austenite is increased; the grain becomes smaller. The hardenability increases for all temperatures above 1000° C. The carbides of tantalum dissociate at about 1000–1100°. The mechanical properties of carbon steel (0·36% of carbon) are improved by the addition of about 0·4% of tantalum, those of alloyed (chromium-nickel) steel remain unchanged. (In Russian).

New Fields for Iron Castings. P. Muguet. (International Foundry Congress, Paris, 1937: Foundry Trade Journal, 1937, vol. 57, Aug. 26, pp. 157–158). After a preliminary discussion on the physical and mechanical properties of cast irons, the author considers the numerous applications of this material in civil engineering work, in domestic appliances, in works equipment and in marine engineering.

Progress in Improvement of Cast Iron and Use of Alloys in Iron. P. D. Merica. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 832: Metals Technology, 1937, vol. 4, Aug., No. 5). After reviewing the development of modern cast irons and examining the present consumption of high-duty irons, the author discusses the structure and characteristics

of the material and indicates how improvements may be effected by modifying melting and casting technique. The effect of alloy additions and heat treatment are dealt with and the general industrial applications of cast iron are considered in detail.

Progress made in Cast Irons for Automotive Applications. H. S. Austin. (American Society for Metals: Foundry, 1937, vol. 65, July, pp. 30–33, 71). The author discusses the heat treatment and manufacture of alloy irons at some length. (*See* p. 244 A).

Ni-Resist in the Chemical and Allied Industries. (Mond Nickel Co., Ltd., Bureau of Information on Nickel, 1937, Publication B 31). The corrosion-resistant properties of Ni-Resist are compared to those of brass and bronze and cast iron, and the resistance to attack shown by the first is examined in more detail subsequently. The heat-resisting properties of Ni-Resist are also considered, and typical applications of the metal in a large number of industries are mentioned.

Properties of Commercial Pure Iron of the "Armco" Type. E. T. Land. (Katshestvennaia Stal, 1936, No. 10, pp. 23–31). Pure iron of the "Armco" type was first produced in the U.S.S.R. on a commercial scale in 1934 in an open-hearth furnace. The author describes the method used and investigates the properties of the product. It contains 0·14 to 0·17% of impurities. The microstructure shows ferrite polyhedra with small islands of free cementite. Pressing at different temperatures reveals an interval of brittleness between 700° and 1050° C., the metal being plastic above as well as below this interval. Rolling, forging and stamping should be carried out at 1300–1050° C., and the rolling of sheets at 800–600° C. The best mechanical properties of sheets are obtained by a thermal treatment (annealing, normalising or hardening) at 900° C. Good plastic properties are also found in cold-rolled and drawn samples, with deformations up to 90%. The critical points are Ac_0 710–715° C., Ac_1 750° C., Ac_2 830–840° C., Ac_3 950–955° C. The recrystallisation is studied by counting the grains after deformation and heating. A diagram showing the size of the grains as a function of the deformation and temperature is drawn. The electrical resistance is 0·104–0·110 ohms per sq. mm. per mm. The maximum magnetic induction is 20,000 gauss with a residual induction of about 10,000 gauss and a coercive force of 1·0–1·35 oersted; the maximum permeability is 2500 gauss per oersted. The magnetic properties suffer by age-hardening, owing to the relatively high oxygen content; it is therefore useful to anneal Armco iron in hydrogen. The heat resistance is found to be somewhat superior to that of ordinary iron; after 240 hr. at 900° the loss in weight was 30% as against 33% found for carbon steel. In the open atmosphere, Armco iron lost (after one year) 0·0341 g. per sq. m. per hr., as against 0·0711 g. lost by steel. The possibilities of the commercial use of Armco are discussed. (In Russian).

Report of Steel Division Committee on Test Coupons. (Trans-

actions of the American Foundrymen's Association, 1937, vol. 45, pp. 97–105). A continuation of a previous report. The effects of casting conditions and of variation in the location of cast-on test-pieces and of preparing separately cast test-pieces on the results obtained in the investigation of the quality of steel castings in plain carbon and alloy steels are discussed.

Diamond Tool Steel. V. A. Erachtin. (Katshestvennaia Stal, 1937, No. 1, pp. 27–31). The author gives a classification of "diamond" steels containing 1·25–1·7% of carbon and 4·0–7·5% of tungsten with: (i) No chromium or vanadium; (ii) no chromium, much vanadium; (iii) much chromium; (iv) medium content of chromium and vanadium. He describes the use of these steels for tools, and gives details of hot mechanical working and thermal treatment of the materials. (In Russian).

The Mechanical Properties of Some Metals and Alloys Broken at Ultra High Speeds. D. W. Ginns. (Journal of the Institute of Metals, 1937, vol. 61). Metals and alloys, including carbon steels, broken at very high speeds in tension exhibit considerably increased yield points with a maximum strength increased by a much smaller amount. The percentage elongation and reduction of area show little change, while the types of fracture obtained are almost identical with those obtained at lower speeds.

Graphitic Steel. G. A. Stumpf and F. R. Bonte. (Iron Age, 1937, vol. 140, Sept. 9, pp. 36–39, 85). The authors describe the physical, chemical and structural characteristics of graphitic steels containing about 1·50% of total carbon and 1·0% of silicon. The heat treatment and fabrication of the material into dies and punches are also dealt with.

Alloy Steels. J. A. Edgerton and P. Mansini. (Bureau of Steel Manufacturers of Australia, 1937, vol. 1, Aug., No. 10). After a preliminary discussion on the development of alloy steels and on various methods suggested for predicting their properties, the authors consider in detail processes utilised for their manufacture, the influence of heat treatment, various alloy steels including copper and silicon steels, stainless steels, possible improvements in alloy steels, and the use and production of alloy steels in Australia.

Trends in Production of American Alloy Steels and of Electric Steels. E. F. Cone. (Metals and Alloys, 1937, vol. 8, July, pp. 191–193). A statistical summary is presented of the steel output of the United States during the last 28 years. The relative figures for electric and alloy steels are studied in relation to total production figures.

Cerium Metal. Production, Properties and Uses. R. Strauss. (Metallwirtschaft, 1937, vol. 16, Sept. 24, pp. 973–975). Reference is made to the use of cerium for removing oxygen, nitrogen, sulphur, and phosphorus from iron and steel. Cerium is best used for this purpose in the form of an alloy containing 5–15% of cerium, 25–60% of aluminium or 5–15% of calcium, silicon or magnesium, and 5–30%

of titanium. The use of a 25–40% vanadium and 40% cerium alloy in the manufacture of vanadium steel is discussed. The properties of the pyrophoric iron-cerium alloys are referred to.

Simplified Alloying for Wear and Corrosion Resistance. M. C. Smith. (Iron Age, 1937, vol. 140, July 15, pp. 35–38). Following a preliminary discussion on the theoretical and practical aspects of wear resistance, the author describes the properties and applications of "Colmonoy" hardener and hard-facing alloy. Its composition is indicated and reference made to its use with steels and cast irons. The hardening constituent consists primarily of a metallic boride.

The Development of German Special Steels on the Basis of Domestic Raw Materials. L. Lammel. (Zeitschrift des Österreichischen Ingenieur und Architekten Vereines, 1937, vol. 89, Sept. 3, pp. 246–248). The author examines the possibilities of replacing particular types of alloy steel, especially those of high-nickel content, by less expensive but equally satisfactory steels containing less nickel or even no nickel. Chromium-molybdenum and chromium-molybdenum-silicon steels are among those considered. Tabular data of the mechanical properties are presented.

Investigation of an Aluminium-Iron Heat-Resisting Alloy. A. S. Saimovsky, N. F. Drosdov and K. V. Nashokin. (Katshestvennaia Stal, 1937, No. 1, pp. 36–40). The authors have investigated an alloy containing 12% of aluminium and 2% of chromium. It is malleable and can be rolled; wire-drawing requires some precautions, because of insufficient toughness. Its electrical resistance is 1·25 ohm per sq. mm. per m., with a temperature coefficient of 3×10^{-4}. It is sufficiently heat-resistant to be used at 1200° C. Wires less than 1 mm. in dia. are easily coiled. On the whole, as a material for resistances, this alloy is superior to nichrome and about equal to megapyr and kanthal. (In Russian).

Heat-Resisting Muffle Equipment. A. L. Fawkes. (Annual Proceedings of the Institute of Vitreous Enamellers, 1937, vol. 3, pp. 174–187). The use of nickel-chromium alloys containing 50–70% of nickel and 15–20% of chromium for perrits is referred to. The importance of using weldable alloys is noted, in order that small failures shall not result in the complete scrapping of heat-resistant castings which are otherwise quite sound.

The Use of Nickel in Automobile Engineering. W. J. Lee-Bird. (Nickel Bulletin, 1937, vol. 10, Aug.–Sept., pp. 169–173). Among the nickel-bearing materials noted and discussed are high-duty heat-treated alloy steels, case-hardening steels, and stainless and heat-resisting steels.

Tests Molybdenum Steel Wheels in Train Service. (Steel, 1937, vol. 101, Aug. 16, p. 82). It is noted that the New York Central Railroad are testing the possibilities of a 0·4% molybdenum steel for coach wheels in order to diminish thermal cracking and failure due to surface hardening.

A Chrome-Molybdenum Carburising Steel. (Alloy Metals Review,

1937, vol. 1, Sept., pp. 53–54). An account is given of the structure and mechanical properties of the chromium-molybdenum carburising steel S.A.E 4120. The early difficulties experienced with steels of this class are noted and the superior properties of the modern type indicated.

Influence of Non-Metallic Inclusions on the Mechanical Properties of Chromium-Molybdenum Structural Steels. I. S. Pilarski and S. Jaźwiński. (Wiadomości Instytutu Metalurgji i Metaloznawstwa, Warsaw, 1937, vol. 4, No. 2, pp. 65–72). Samples of structural chromium-molybdenum steel containing approximately 1·0% of chromium and 0·3% each of carbon and molybdenum were prepared by the duplex process in the electric furnace. The 600-kg. ingots obtained were rolled to bars 30 mm. in dia. and test-pieces cut parallel to the direction of rolling. Impurities were determined microscopically. Grain size, tensile strength, impact strength, and fatigue strength were determined. Tabular and graphical data are presented.

Chromium-Nickel-Molybdenum Structural Steel with 1·5% of Nickel. V. A. Erachtin. (Katshestvennaia Stal, 1936, No. 10, pp. 39–44). The paper describes the properties of a structural steel with only 1·25 to 1·75% of nickel (besides 0·6 to 0·9% of chromium and 0·15 to 0·25% of molybdenum), which may be used as a substitute for nickel steels. The best hardening temperature is 850° to 875°. Tempering changes the properties in the usual way, but the impact resistance decreases sharply in the interval 200° to 500°. The average mechanical properties are: Tensile strength, 100 kg. per sq. mm.; impact resistance, 10 kg. per sq. cm.; elongation, 12%; contraction of area, 50%. The mechanical properties are independent of the size of the austenite grains. (In Russian).

Mayari R, a Corrosion Resistant, High Strength Steel. R. S. A. Dougherty. (Iron Age, 1937, vol. 140, Sept. 9, pp. 44–48). **New Low Alloy Steels with Unusual Properties Are Results of Research.** R. S. A. Dougherty. (Steel, 1937, vol. 101, Sept. 13, pp. 36–39). The author describes the properties, manufacture and uses of the low-alloy structural steel Mayari R containing carbon 0·08%, manganese 0·45–0·72%, phosphorus 0·099–0·10%, sulphur 0·035–0·042%, silicon 0·10–0·40%, nickel 0·33–0·34%, chromium 0·25–0·56%, copper 0·5–0·62%. The composition varies according to the form in which the steel is required. The yield point of these steels varies between 50 and 55 $\times$ 10^3 lb. per sq. in., and the minimum tensile strength between 65 and 75 $\times$ 10^3 lb. per sq. in.

French Technicians on High-Duty-Steel Reinforcing. (Annales de l'Institut Technique du Bâtiment et des Travaux Publiques, Mar.–Apr., 1937: Zeitschrift des Österreichischen Ingenieur und Architekten Vereines, 1937, vol. 89, Sept. 3, pp. 246–248; Sept. 17, pp. 263–264; Oct. 1, pp. 275–276). The use of alloy steel for reinforcing concrete structural work is considered in the light of

the mechanical properties of both the steel and the concrete. Nickel-chromium steel is referred to.

Building Inspection and Material Testing Departments. M. Roš. (Revue Technique Luxembourgeoise, 1937, vol. 29, May–June, pp. 52–58). A review is presented of decrees and standards respecting the safety of structural work, containers for compressed gases, and pylons for electrical transmission lines. Included in the tabulated data are standard values for the mechanical properties required in steels employed for these purposes.

Investigation of Chromium-Manganese-Copper Steel for the Building of the Palace of Soviets. I. S. Guinsburg. (Katshestvennaia Stal, 1937, No. 1, pp. 32–35). (In Russian).

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(Continued from pp. 246 A–249 A)

Vickers Projection Microscope. (Wild-Barfield Heat-Treatment Journal, 1937, vol. 2, Sept., pp. 81–84). Constructional and operating data are presented regarding the Vickers projection microscope. This instrument was designed primarily for photomicrographical work in connection with metallurgy.

The Stereographic Projection. C. S. Barrett. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 819 : Metals Technology, 1937, vol. 4, Aug., No. 5). The author presents an elementary explanation of the principles and methods of stereographic projection, covering all the common applications in the field of metallography and physical metallurgy.

Crystalline Manganese Sulphide in Chilled Cast Iron. O. W. Ellis. (Metals and Alloys, 1937, vol. 8, Aug., pp. 221–223). The author notes the occurrence of manganese sulphide in chilled iron, and describes its appearance, means of detection and the cause of its presence.

Macrostructure of Cast Iron. K. F. Starodubov and F. M. Gorbacheva. (Metallurgist (Russia), 1936, No. 12, pp. 89–94). The authors have investigated the macrostructure of a cast iron mould by etching with Baumann's reagent and Heyn's reagent. The first reveals a dendritic structure, orientated transversely in a 25-mm. thick surface layer, and chaotic in the inside. This is the primary structure. Heyn's method shows the globular secondary structure. (In Russian).

Primary and Secondary Structures of a Small Ingot of Hypereutectoid Carbon Steel (1·28% Carbon) as Cast, Annealed, Water-Quenched and Decarburised. J. Seigle. (Chimie et Industrie, 1937, vol. 38, July, pp. 13–19). The author explains the technique of studying the structures of a 1·28% carbon steel ingot, and describes and discusses experimental work on the effect on the structures of annealing, quenching, and decarburising by heating in air at 1050° for 40 min.

Inverse Segregation : A Review. N. B. Vaughan. (Journal of the Institute of Metals, 1937, vol. 61). The literature relating to inverse segregation is reviewed and the nature of the phenomenon described. A selection of published experimental data is presented to illustrate the influence of factors which vary the extent of inverse segregation, such as temperature of casting, pouring speed and mould material. Theories put forward to account for the phenomenon are summarised but no attempt is made to appraise them.

Some Observations on the Structure of Slowly Cooled Steel Test-Pieces. M. Śmiatowski. (Wiadomości Instytutu Metalurgji i

Metaloznawstwa, Warsaw, 1937, vol. 4, No. 2, pp. 58–60). The purpose for which this work was undertaken was to test the application of the Tammann-Bridgman method to the growing of large ferritic and austenitic alloy crystals. Difficulty was experienced in obtaining homogeneous mixtures of the constituents in preparing the test-pieces. High-manganese and chromium steels were investigated.

State of Carbon in Solid Solution in Iron. T. A. Lebedev. (Metallurgist (Russia), 1936, No. 12, pp. 59–63). The author has determined the difference in heating velocity of two hollow iron cylinders, both of which contained the same quantity of iron filings mixed with carbon powder (with 10% of soda), but in one of which the filings were copper-plated to prevent carburisation. The arrest in the temperature curve of the non-plated filings in the region 900–1050° C. indicates the endothermicity of the carburisation. This result the author compares with the known absence of thermal effects in the decomposition of hypereutectoid solid solutions into cementite and ferrite, and concludes that the endothermic effect of the carburisation process is due to the formation of cementite molecules. The carburisation thus comprises the endothermal formation of Fe_3C and the diffusion of Fe_3C into the iron lattice, which does not involve measurable changes in energy. It has been argued that Fe_3C molecules are too large for diffusion; the author assumes that carbon atoms migrate as such, but form Fe_3C molecules (without a thermal effect) as soon as they are stopped somewhere in the lattice. (In Russian).

Accelerated Method of Determination of the Size of Austenite Grains. (Katshestvennaia Stal, 1936, No. 10, p. 49). Comparative determinations of the size of austenite grains in ten different special steels by the usual method and by the new method of the Ural Institute of Metals (*see* p. 160 A), showed that the latter is not suitable for the control of the grain size in special steels. (In Russian).

Cast Ni-Cr Heat Resisting Alloys. F. K. Ziegler and L. B. Haughwout. (Metals and Alloys, 1937, vol. 8, Aug., pp. 225–229). The authors comment on the difficulties caused in etching for grain size by the carbide constituents present in the commercial casting alloys containing 35–65% of nickel and 15–20% of chromium together with 0·40–0·75% of carbon. For microscopic grain-size determinations a chromic-acid/hydrochloric-acid etching reagent is suggested.

Control of Grain Size in Carbon Steels and Special Steels During Melting. M. A. Elinson, L. L. Soloviev and I. I. Penieguin. (Katshestvennaia Stal, 1937, No. 1, pp. 7–14: Stahl und Eisen, 1937, vol. 57, Apr. 22, pp. 422–423). The paper contains a description of the methods developed at the Zapozoshje Steel Works for controlling the grain size in different stages of the melting process. The materials tested were carbon tool steels, tungsten tool steels, ball-

bearing steels, chromium-nickel and chromium-molybdenum steels, &c.; 13 sample ingots were cast in the course of each melting process. The grain size, anomalies of the pearlite structure and hardenability were investigated for each of them. Aluminium has the strongest effect in reducing the grain size, especially when added at a late stage of the process. In the case of tungsten steels, when large grains and a correspondingly deep hardenability are required, the quantity of aluminium used must be as small as possible. Numerous other suggestions are made concerning the processes to be used to obtain steels with the grain size desired.

Influence of Cold Work on Austenitic Grain Size. A. M. Portevin. (Metal Progress, 1937, vol. 32, Aug., pp. 166–167). The author describes experiments indicating the effect of cold-work upon grain growth as defined by the McQuaid-Ehn test.

Recrystallisation of Steel by Deformation at High Temperatures. I. M. Pavlov, L. S. Gelderman and A. I. Shukova. (Metallurgist (Russia), 1936, No. 12, pp. 3–14). The authors have investigated the grain size of two carbon steels (0·40 and 0·54% of carbon) after deformation by hammering at 800–1150° C., *i.e.*, above the A_3 transformation point. Cylindrical samples (dia. 2 cm., height 3 cm.) were heated for 15 min. to the temperature desired, deformed by a single blow of a 100-kg. hammer, kept at the same temperature for another 40 min. to allow the recrystallisation to proceed to the end, and cooled in air. The grain size (*i.e.*, the size of the cementite network enclosing pearlite grains) was determined separately on 12 planes in each sample. The deformation corresponding to each plane was calculated by measuring the change in distance between the consecutive threads of a screw inserted into the sample parallel to its axis and deformed with it. The deformation was greater in the centre of the sample than near the end faces; the grain size was accordingly different on different planes. The authors give three-dimensional diagrams showing the grain size as a function of true local deformation (5–85%) at different temperatures. For comparison, curves showing the grain size in the centre of the sample as a function of the average deformation of the sample as a whole are also given, this being the only kind of data determined by previous investigators. The "true" curves show a higher maximum of grain size near the "critical" deformation than the "average" ones. The critical deformation is less than 10% at 800° C., and becomes practically zero at 1100° C. The largest grain was therefore observed in the region of the smallest deformation—*i.e.*, near the end faces of the sample—and not in the centre, as assumed by Hanemann and other investigators. With the deformation increasing above the critical value, the grain size decreases to a constant limiting value, which is the larger the higher the temperature. At the highest deformations used (85%) the grain size was sometimes observed to increase again. The grain size after deformation depends very much on that before the treatment. By allowing

the grain to grow at different temperatures above 900° C., the authors prepared samples in which the grain size, after cooling from 900° without mechanical treatment, varied from 3000 to 9000 sq. μ. These samples, after a deformation of 26% at 900° C., showed grain sizes of from 4300 to 10,100 sq. μ. In order to obtain a small-grain structure in carbon steels hammered above 800° C. it is therefore necessary (*a*) to ensure the smallest grain size of the material used by an appropriate preliminary treatment, and (*b*) to use deformations of not less than 20%, to avoid the critical region of marked grain growth. (In Russian).

Linear Velocity of Growth and the Velocity of Formation of Nuclei in the Secondary Crystallisation of Special Steel. I. L. Mirkin and M. E. Blanter. (Metallurgist (Russia), 1936, No. 12, pp. 43–50). The authors have determined the linear velocity of growth and the velocity of formation of nuclei in a steel containing 0·98% of carbon, 0·56% of manganese, 0·35% of silicon, and 1·16% of chromium by a new statistical method based on Scheil's calculations.

The Appearance of Coarse Grains on Annealing Normalised Thin Sheet. F. Eisenkolb. (Stahl und Eisen, 1937, vol. 57, Sept. 9, pp. 999–1001). The coarse structure occasionally obtained on annealing thin sheets of normalised mild steel was examined in relationship to the velocity of cooling after normalising and to the annealing temperature. It is shown that the foreign matter always present remains in solution with rapid cooling and hence does not inhibit grain growth. Thermal stresses also are shown to favour grain growth. In the correspondence attaching to this paper, Busson advances a further explanation based on supersaturation of the ferrite with carbon on rapid cooling, and on the consequent stressed condition which this occasions; tabular data are presented.

Preferred Orientations in Iron-Silicon Alloys. C. S. Barrett, G. Ansell and R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 813: Metals Technology, 1937, vol. 4, Aug., No. 5). The author examines the preferred orientation in cold-rolled silicon-iron alloys containing 2·07% to 4·61% of silicon. Textures differ only in the amount of scatter around the rolling direction as an axis, and resemble those previously reported for iron, mild steel and iron-nickel alloys.

Martensite Transformation in High-Speed Steel. A. P. Guliaiev. (Katshestvennaia Stal, 1937, No. 1, pp. 41–47). The author has investigated the influence of the temperature of hardening and of the duration of heating before hardening on the temperature of the transformation of austenite into martensite. The higher the hardening temperature and the longer the heating, the lower is the transformation point. The transformation occurs not at a single point, but over an interval of which the end point lies above room temperature for steels with 0·3 to 0·4% of carbon, but is often below room temperature for steels with high carbon contents. In these latter steels, the transformation is often incomplete, and residual

austenite remains after hardening. The position of the point where the martensite transformation begins is the essential factor determining the structure and properties of steel. The maximum hardness of high-speed steel is obtained by adjusting the heating time before hardening so that the transformation begins at 150° C. If transformation begins above this temperature, the solution of the carbides is incomplete; if transformation beings below 150° C., untransformed austenite is left in the steel. (In Russian).

Austenite-Martensite Transformation Laws. J. A. Kazejev. (Metallurgist (Russia), 1936, No. 12, pp. 51–58). The author describes his own experiments and those of other investigators on the kinetics of the decomposition of austenite in chromium-nickel and chromium steel. Inflections on the cooling curves occur not exactly at the points corresponding to the beginning of the transformation—as revealed by the appearance of the magnetic phase—but somewhat later, when the velocity of the transformation becomes high enough for the heat of reaction to compensate for the loss of heat by cooling. The author applies to the experimental data a kinetic formula, $\log_e (A/A_0) = -at^n$ (a and n = constants, A = quantity of austenite present at the time t) and finds that the transformation of chromium steel occurs in two stages. The first one, with a larger value of n, corresponds to an austenite-troostite transformation, the second one to an austenite-martensite transformation. The author also discusses the influence of the cooling velocity on the quantity of residual austenite; quick cooling in water causes stronger stresses and therefore a more complete disappearance of austenite than slower cooling in oil. A high content of carbon (*e.g.*, 1·6%) stabilises the austenite at low temperatures and increases the quantity of residual austenite. The increase is relatively highest in the case of quick cooling. (In Russian).

Influence of the Temperature of Heating and of the Grain Size on the Velocity of Transformation of Austenite and on the Hardenability. S. S. Steinberg, V. V. Skluiev and S. S. Nossyreva. (Katshestvennaia Stal, 1937, No. 1, pp. 21–23). The paper contains a description of two series of experiments concerning the influence of the overheating of steel before hardening on its hardenability. (1) The velocity of breakdown of the austenite is measured microscopically at 250° to 650° C. using samples hardened from 800° both with and without preliminary heating to 1100°. Preheating is found to increase the duration of the incubation period before breakdown as well as that of the decomposition itself, by a factor of 3–4. (2) The velocity of the breakdown of austenite is measured in samples in which the size of the austenite grains has been changed by plastic deformation. It is found that the increase in grain size affects only the number of decomposition nuclei, but leaves both the incubation period and the velocity of growth of pearlite-troostite grains unchanged. Comparison of (1) and (2) shows that preheating to 1100° not only increases the size of the austenite grains, but also

influences the inherent stability of the austenite, probably by increasing the orderliness of the lattice. This causes the region of complete hardening (martensite structure) to expand, whereas the increase in grain size causes an extension of the region of mixed troostite-martensite structure (incomplete hardening). (In Russian).

Relationship Between the Velocity of the Austenite Transformation and the Deoxidation Process. H. Krainer. (Zeitschrift für Elektrochemie, 1937, vol. 43, pp. 503–509: Stahl und Eisen, 1937, vol. 57, Sept. 2, p. 986). The results of investigations are described which were carried out on an acid high-frequency steel to ascertain the effect of inclusions introduced as a result of the addition of deoxidising agents on the formation of nuclei to initiate the γ–α transformation. Not only the quantity but also the distribution of non-metallic inclusions is shown to be of importance; the latter is dependent on the ferrous oxide content of the bath prior to the addition of the aluminium used for deoxidation.

The Constitution of Manganese Steels. (Metallurgist, 1937, vol. 11, Aug. 27, pp. 55–58). An English summary of a paper by W. Tofaute and K. Linden in Archiv für das Eisenhüttenwesen, 1937, vol. 10, May, pp. 515–524. (*See* p. 96 A).

CORROSION OF IRON AND STEEL

(Continued from pp. 250 A–251 A)

Some Long-Time Corrosion Tests on Metals. J. C. Hudson. (Métaux et Corrosion, 1937, vol. 12, June, pp. 109–118). After a brief reference to corrosion investigations carried out by the Institution of Civil Engineers, the British Non-Ferrous Metals Research Association and the Corrosion Committee of the Iron and Steel Institute, the author discusses the present state of knowledge on the corrosion of metals and alloys exposed to the open air and compares their corrosion resistance. The variation in corrosion with duration of exposure and the protection of ferrous metals by paints are also considered. Tabular data are presented based on the researches carried out by the Corrosion Committee of the Iron and Steel Institute and other bodies.

The Atmospheric Rusting of Iron. II. G. Schikorr. (Zeitschrift für Elektrochemie, 1937, vol. 43, Aug., pp. 697–704). The author has continued his study of the atmospheric corrosion of iron under field conditions. (*See* Journ. I. and S.I., 1936, No. II, p. 272 A). One of his methods consists in exposing small emeried specimens for consecutive periods of one month and comparing the sums of the monthly values for the losses in weight with those observed for similar specimens exposed throughout the same periods. Comparison of the two types of corrosion time curves obtained in this manner for mild steel, electrolytic iron and cast iron exposed under several different conditions for periods of up to two years shows that in the case of specimens freely exposed in the open at Berlin-Dahlem, where the atmosphere is fairly highly polluted, the rust formed on electrolytic iron and mild steel exerts an undoubted protective effect. The protective effect of the rust is less in less polluted atmospheres and in cases where the specimens are freely exposed but protected from rain. Moreover it is less marked for cast iron than for the electrolytic iron or mild steel. An important feature of the work is that full meteorological observations are taken throughout the tests. The author has now extended these to include monthly determinations of the sulphur content of the air by Liesegang's method (Kleine Mitteil. der Preuss. Landesanstalt f. Wasser-Boden-u Lufthygiene, 1932, vol. 8, p. 174). A marked parallelism was observed between the values for the sulphur content of the air and the monthly rates of rusting, excepting for months in which prolonged frosty periods occurred. The sulphur content of the air was much higher in winter than in summer, the ratio for Berlin-Dahlem being 10 : 1. The dew deposited on the rusted specimens in autumn was found to contain up to 1 g. of SO_3 per litre, which is equivalent to an $N/50$ solution. Most of the sulphuric acid in the dew was present, however, in the combined form,

for although it was distinctly acid to litmus, it did not turn methyl-orange red. Dew deposited on glass plates was found to contain only 0·16 gr. of SO_3 per litre, and the author therefore considers that rust adsorbs sulphuric acid from the atmosphere during fine periods. Experiments on the effects of previous exposure to rusting in different atmospheres on subsequent corrosion in a closed atmosphere of 93% relative humidity showed that rusting under these conditions was closely connected with a sulphur content of the pre-rusting atmosphere. Thus specimens pre-exposed in a locomotive shop developed in the closed atmosphere the very high rate of rusting of 10 gr./m.^{2}/day. An average figure for Sheffield over a year's exposure would be *c.* 3 gr./m.^{2}/day.

Corrosion Under the Influence of Falling Drops of Corrosive Liquids. G. Welter and S. Gockowski. (Wiadomości Instytutu Metalurgji i Metaloznawstwa, Warsaw, 1937, vol. 4, No. 2, pp. 73–78). Experiments were carried out to determine whether the speed of the falling drops of corrosive fluid affected the course of a corrosive action. In practice, seaplane floats, airplane screws, &c., are subjected to influences of this type, often up to speeds of 50 m. per sec. Sodium chloride solution (3%) was allowed to fall from various heights on to the specimens of non-ferrous metals, and the results were compared with normal corrosion phenomena.

Sea-Water Corrosion. (Académie Méditerranéenne, Monaco, 1937, No. 6). The following papers were presented at a congress on sea-water corrosion held in Mar. 1937 :

GRARD : Causes and Progress of Marine Corrosion of Metals and Alloys used in Aircraft.

The author deals mainly with the physico-chemical bases of corrosion and means of investigating them.

R. LEGENDRE : Bacteriological Aspects of Corrosion.

The action of thiobacteria on iron is noted.

SIR ROBERT HADFIELD : On Corrosion.

Reference is made to the work of the Corrosion Committee of the Iron and Steel Institute.

J. C. HUDSON : Long Time Corrosion Tests.

G. CHAUDRON : The Function of the Active-Metal/Passive-Metal Couple in Sea-Water Corrosion.

Experimental work and discussion on the fundamentals of marine corrosion.

L. DELVILLE : Problems in the Systematisation of Researches on Corrosion and the Protection of Metals and Structural Materials.

A general sketch of the theory and mechanism of corrosion and of methods of investigating the processes occurring.

LECŒUVRE : Corrosion of Metallic Structures.

The riveting of 18/8 chromium-nickel steel to light alloys with cadmium-plated rivets is noted.

A. MICHEL : Researches on Stainless Steels.

The structure, analysis, and corrosion resistance of a number of chromium and nickel-chromium stainless steels are discussed.

TRAVERS : The Graphitisation of Cast Irons.

The author discusses the mechanism of a peculiar process of corrosion suffered by cast iron deeply submerged in sea-water, or in a poorly aerated situation.

M. SAUVAGEOT and R. MARCHAND : Influence of Temperature on the Corrosion of Various Metals by Salt Spray.

Tests were carried out on very low carbon and 3% chromium steels.

A. PORTEVIN and E. HERZOG : Comparison of Field and Laboratory Tests on the Marine Corrosion of Certain Very Mild Steels and of Mild Steels with Small Additions of Special Elements.

The results obtained on a low chromium-aluminium steel are tabulated.

MISS M. T. FRANÇOIS : Chinese Wood Oil in the Defence Against Corrosion.

The use of tung oil varnishes for protecting steel is noted.

C. BENEDICKS : Regarding the Influence of Sea-Water and Other Meteorological Variables on the Corrosion of Iron and Steel.

An analysis is presented of data published by Hadfield and Main.

SOCIÉTÉ NOUVELLE DE MÉTALLISATION : Protection Against Corrosion by Means of Metallic Coatings.

A brief report on the corrosion characteristics of steel test-pieces sprayed with zinc, aluminium, cadmium, lead, &c.

F. CANAC : Study of the Topography of Corroded Surfaces.

A method is described for following the course of a corrosion process by a continuous determination of the reflectivity of the surface concerned by means of a photo-electric cell.

P. NICOLAU : Measurement of Surface Condition by means of the Solex Micrometer.

The Solex "manometric" micrometer is described and its use in plotting surface contours discussed.

M. PROT : The Rôle of Superficial Films in Corrosion Phenomena.

The function of combined or adsorbed films in corrosion processes is noted.

Processes of Attack on Heat-Resisting Steels by Hot Gases. E. Houdremont and G. Bandel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Sept., pp. 131–138). It is known that the resistance of heat-resisting steels to burning in air is due to the formation on the surface of a protective layer composed of the oxides of the alloying elements present in the steel. This oxide film must possess good mechanical adhesion, be free from porosity, and must be

highly impermeable. Its formation and maintenance are conditioned by the constant and extensive transportation of the effective elements to the surface by diffusion, so that oxygen penetrating the protective layer is completely fixed. The effectiveness of the protective coating will depend largely upon the degree to which these conditions are fulfilled. The constant diffusion of the alloying elements to the surface is governed by the content of the alloying elements, temperature, structure, oxidation of alloying elements at the surface and interference with the continuance of the diffusion process by inclusions. In the present investigation the effects of the individual alloying elements, chromium, nickel and aluminium were studied, and the processes of attack in air, oxygen, superheated steam, carbon dioxide, carbon monoxide, hydrogen, sulphur dioxide, hydrogen sulphide, sulphur-bearing commercial gas, ammonia and nitrogen were examined. Processes of attack by superheated steam, and by sulphur-bearing gases, and the effect of nitrogen adsorption, were studied particularly closely in the case of many steels.

Recent Studies of Intergranular Corrosion in Nickel-Chromium Steels. (Wire and Wire Products, 1937, vol. 12, Sept., pp. 469–473). An English translation of a paper by P. Chevenard in Métaux et Corrosion, 1937, vol. 12, Feb., pp. 23–31. (*See* p. 51 A.)

ANALYSIS

(Continued from pp. 106 A–109 A)

The Sampling of Alloying Materials Containing Tungsten, Molybdenum and Vanadium. (Alloy Metals Review, 1937, vol. 1, Sept., pp. 49–51). An account is given of the method of sampling ferro-alloys employed by High Speed Steel Alloys, Ltd. The procedure is designed to eliminate variations in the results of analyses made by the buyer and seller of the alloys.

Determination of Iron with 7-iodo-8-hydroxyquinoline-5-sulphonic Acid. H. W. Swank and M. G. Mellon. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Sept. 15, pp. 406–409). The authors describe an investigation to determine the conditions under which the "ferron" method of estimating iron colorimetrically yields the best results. The orange aqueous solution becomes green in the presence of ferric salts. Other metals interfere with the reaction and in some cases must be removed before estimating the iron.

A Wood's Metal Reductor. G. F. Smith and C. S. Wilcox. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Sept. 15, pp. 419–420). The authors discuss the advantages of using Wood's metal in the reductor, and describe the technique of determining iron (in iron ores), and iron in the presence of titanium.

The Direct Photo-Electric Determination of Manganese and Chromium in Steels. G. Thanheiser and J. Heyes. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, July, pp. 31–40: Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 9, pp. 113–122). In the method of estimation described, the intensity of the spectral lines of the manganese and chromium in the steel is measured by means of a photo-electric cell and electrometer, and in this way the amount of these elements in the steel can be determined. The spectral lines are generated by means of a compressed-air/acetylene flame, into which the dissolved specimen is injected by means of an atomiser. In the concentration range 0–400 mg. per litre, the photo-electric current is proportional to the concentration. The results of a series of analyses made by the new method are recorded, and their good agreement with the results of ordinary chemical analyses is demonstrated. The presence of other elements does not interfere with the results. The manganese determination can also be applied to the examination of aluminium alloys.

The Phosphotungstate Method for Vanadium. E. R. Wright and M. G. Mellon. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, June 15, pp. 251–254). The authors have made a spectrophotometric study of the phosphotungstate method

for vanadium for the purpose of ascertaining the optimum concentration of reagents, the effect of acid and diverse ion concentrations, and the stability. Typical transmittancy curves are given covering the most useful range of concentration. Procedures are proposed for the application of the method to the determination of vanadium in alloy steels.

Interference Measurements of Wave-Lengths in the Ultra-Violet Spectrum of Iron. W. F. Meggers and C. J. Humphreys. (Journal of Research of the National Bureau of Standards, 1937, vol. 18, May, pp. 543–557). The wave-lengths of 252 ultra-violet lines (3498 to 2101 Å.) characteristic of the international iron arc were measured relative to cadmium, krypton or neon standards. These measurements were made with Fabry-Perot étalon interferometers and stigmatic spectrographs. Invar étalons of 2, 3, 5, 7·5, or 10 mm. length, and aluminised quartz plates were used. The spectrographs consisted of a concave grating, a Littrow quartz, or a Cornu quartz instrument. With the first, simultaneous exposures were obtained of red neon lines in the first-order spectrum, and of ultra-violet iron lines in the overlapping second-order spectrum. The use of quartz spectrographs required alternate exposures of primary and secondary sources. The final values in many cases are given to eight figures, since calculations of probable error and tests of relative value by means of the combination principle indicated average errors smaller than 0·0005 Å.

25 Determinations on Cast Iron in 25 Minutes. F. J. Oliver. (Iron Age, 1937, vol. 139, May 20, pp. 25–29). A short account is given of the equipment and methods used by Campbell, Wyant and Cannon Foundry Co., Muskegon, Michigan, for the spectrographic analysis of cast iron.

Spectroscopic Determination of Metals in Small Samples. D. T. Ewing, M. F. Wilson and R. P. Hibbard. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Sept. 15, pp. 410–414). Among the metals investigated by the authors are manganese, iron and phosphorus.

Quantitative Emission Spectrum Analysis. K. Cruse. (Angewandte Chemie, 1937, vol. 50, May 29, pp. 397–400). After a short general summary on quantitative spectrum analysis, the author discusses the various sources of error that may arise, in the specimen, in the experimental arrangement, and in the photographic plates, and their evaluation. Finally, he gives a brief description of a generally applicable method of making quantitative spectrum analyses.

A New Method for the Indirect Volumetric Determination of Nickel. S. Ishimaru. (Science Reports of the Tôhoku Imperial University, 1936, Oct., Professor K. Honda Anniversary Volume, pp. 493–500). The author liberates dimethylglyoxime from the nickel-dimethylglyoxime compound, and decomposes this with a known excess of decinormal dichromate which is then determined

by back-titration with ferrous-sulphate/permanganate, or by ferrous sulphate potentiometrically. He finds that 1 c.c. of decinormal potassium dichromate is equivalent to 0·00024 g. of nickel. Limitations of the method are indicated.

The Use of Perchloric Acid in the Steelworks Laboratory. A. Seuthe and E. Schaefer. (Archiv für das Eisenhüttenwesen, 1937, vol. 10, June, pp. 549–551). The authors describe the advantages of the use of perchloric acid as a combined solvent and oxidising reagent, and give details of methods of estimating silicon, phosphorus, chromium and vanadium for use in steelworks laboratories where perchloric acid is employed.

An Improved Method for Determining Gas Content of Molten Steel. W. Hare, L. Peterson and G. Soler. (Transactions of the American Society for Metals, 1937, vol. 25, Sept., pp. 889–903). The authors describe a rapid method for analysing the gas content and accurately calculating the iron oxide in molten steel at any stage of the working of a heat. The apparatus used is described and the method of sampling, analysing and calculating the gas or iron oxide content is outlined. The method has proved useful in determining the degree of deoxidation in electric furnace and open-hearth steel and the effect of various deoxidation practices and slags on the amount of iron oxide present.

Contribution on the Determination of Gases in Steel by the Hot Extraction Method. G. Thanheiser and H. Ploum. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Aug., pp. 81–88 : Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 8, pp. 105–112). The methods of analysing the gases extracted from steels by the hot extraction method are described; attention is directed to the sources of error in the volumetric gas apparatus and in the method for estimating hydrogen and nitrogen. A series of experiments, in which gas mixtures of various compositions were analysed by combustion in the explosion pipette, in the platinum capillary and by passage over copper oxide, showed that for accurate gas analysis the explosion pipette is unsuitable, owing to the simultaneous combustion of nitrogen; the platinum capillary is superior. The authors have developed a suitable gas analyser. Comparative nitrogen estimations by the hot extraction and solution methods indicate that the platinum capillary is adequate for the determination of gases in steels. Finally, the manipulation of the gas analyser is described.

On Some Improvements of the Electrolytic Methods of Extracting Slag Inclusions from Iron and Steel. A. Skapski, B. Berhang and A. Kotliński. (Annales de l'Académie des Sciences Techniques à Varsovie, 1936, vol. 3, pp. 219–228). After briefly indicating the weak features of the electrolytic methods of separating non-metallic inclusions proposed by Benedicks and by Fitterer, the authors describe the attempts made by one of them to improve upon them, the object being to reduce the heavy attack of the

electrolyte in Benedicks' method which causes low values for substances containing manganese, and to remove the contaminating iron salts from the slag residue produced in Fitterer's method so as to enable direct determinations of the FeO to be made.

The Application of Electrolysis to the Determination of Non-Metallic Inclusions in Steel. L. Biket and F. Williams. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Sept., pp. 125–130). A new type of electrolytic apparatus is described by which it is possible simultaneously to recover the iron which goes into solution during the course of the analysis in the metallic form. It is possible with this apparatus to maintain the *p*H value of the solution constant and thus to avoid the disturbance caused by the precipitation of iron hydroxide. The preparation and composition of the electrolyte required are described. The results obtained by this method are compared with those obtained by other methods. It was found that certain fundamental errors are associated with the new method which render it at the moment unsuitable for use in practice. The disturbing effect of nickel is noted and a method is described for avoiding it. It could not be decided whether colloidal silica was formed or whether it was completely removed by soda solution. No solvent for nitrides has been found.

Analytical Control of Chromium-Plating Solutions. E. E. Halls. (Metallurgia, 1937, vol. 15, Feb., pp. 105–107). The author outlines methods for determining the chromic acid and the sulphuric acid contents of chromium-plating baths. Information on the determination of trivalent iron and chromium is also given.

The Sampling of Coal. L. A. Bushell. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 37, Feb., pp. 361–434). In this lengthy paper the author critically reviews previous work on coal sampling, and presents a complete study of the best conditions and methods of sampling for use with all commercial grades of South African coal. Specifications for the sampling of both large and small coal are suggested. An investigation of the accuracy of a mechanical drill sampling machine for the sampling of large coal was carried out, and a direct comparison between hand and drill sampling was made. Based on experimental evidence a mathematical expression incorporating all the variable factors (namely, the probable error, the heterogeneity of the coal, the size of the coal and the weight of the increment) encountered during the taking of random increments from quantities of coal has been developed. This relationship is shown to be applicable in all cases.

The Problem of Coal Sampling. C. W. H. Holmes. (Colliery Guardian, 1937, vol. 154, June 4, pp. 1049–1052; June 11, pp. 1097–1099). The author discusses the problem of coal sampling from the technical and practical, and the producers' and consumers' points of view.

Elementary Analysis of Solid and Liquid Fuels. M. Véron. (Chaleur et Industrie, 1937, vol. 18, July, pp. 287–294). The

author indicates briefly the general purpose of fuel analysis, and describes the technique and apparatus for estimating carbon, hydrogen and nitrogen by the combustion method. An independent analytical method for carbon alone is also given.

Determining Ash in High-Carbonate Coals. O. W. Rees. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, July 15, pp. 307–309). The author describes investigations to determine the ash and mineral matter by the modified method of Parr in high-pyrites and calcium carbonate coals. An attempt is made to elucidate the difficulties experienced in the application of this method. It is concluded that sulphur trioxide (in excess of that required by the calcium sulphate) is not expelled in 3–5 min. at 750° C.; that losses probably occur owing to decomposition of iron and aluminium sulphates; that the dissociation of calcium sulphate is not materially increased by increased temperature from 750° C. to 1000° C., or by increased duration of heating from normal periods to 110 min.; and that Parr's procedure may be modified with advantage to include heating of the sulphated samples to constant weight, *i.e.* for 15–20 min.

A Rapid Method for Determining the Moisture Content of Small Coal. G. J. Greenfield and G. A. Dummett. (Fuel in Science and Practice, 1937, vol. 16, June, pp. 183–188). A description is given of a volumetric method for determining the moisture content of small coal in five minutes with an accuracy for one determination of one part in forty.

New Apparatus for Technical Gas Analysis. E. Schierholz. (Glückauf, 1937, vol. 73, Sept. 18, pp. 875–876). A description is given of a new portable type Orsat apparatus suitable for the testing of blast-furnace, producer, coke-oven, and coal gas, and smoke.

Gas Analysis in the Orsat Apparatus. Gehle. (Angewandte Chemie, 1937, vol. 50, Aug. 14, pp. 693–695). The author describes the determination of methane and ethane by means of activated palladium, and presents a simple design for Orsat's apparatus. Results are discussed in relation to coal gas.

BOOK NOTICES

(Continued from pp. 207 A–210 A)

ARCHBUTT, S. L., and W. E. PRYTHERCH. "*The Effect of Impurities in Copper.*" With a Foreword by H. W. Brownsdon and an Introduction by C. H. Desch. (British Non-Ferrous Metals Research Association. Research Monograph, No. 4.) 8vo. pp. xvi + 134. Illustrated. London, 1937: The Association. (Price 12*s.* 6*d.*)

A study of the effects of impurities in copper was the first investigation undertaken by the British Non-Ferrous Metals Research Association when it was formed seventeen years ago. The work was carried out at the National Physical Laboratory and continued for many years. The effects of various elements and combinations of elements were investigated in turn, and the results were made known to members of the Association in a series of more than twenty reports of which eight have been published in the Journal of the Institute of Metals. The object of the present publication is to summarise and review the whole of the work in the light of the latest knowledge, to set out the final conclusions reached and to present a connected account of the whole subject. The book begins with an account of the preparation of the materials studied and the methods used in determining their properties, *i.e.*, tensile, notched-bar, reverse bend, and fatigue tests, and measurements of density, electrical conductivity, and softening temperature. This is followed by a short chapter on commercially pure copper in which sample analyses of electrolytic tough pitch and oxygen-free high-conductivity coppers are given. A table of the properties of five samples of high-purity copper is also included. Following this, detailed accounts of the effects of impurities are given in six chapters, which deal with the individual effects of oxygen, hydrogen, sulphur, phosphorus, silicon, bismuth, lead, arsenic, antimony, nickel and silver, and with the combined effects of oxygen and hydrogen, oxygen and bismuth, oxygen and lead, arsenic and antimony, nickel and antimony, bismuth and arsenic, &c. The penultimate chapter is concerned with the segregation of impurities in large works ingots, and the book ends with a chapter on the comparative effects of impurities on the mechanical and physical properties of copper. Here graphs are given, showing the effects of varying amounts of the different impurities on the ultimate tensile strength, elongation, endurance limit, conductivity and softening temperature. Throughout the work numerous tables are provided, in which the results of all the tests are set out in detail.

J. M. ROBERTSON.

CASTRO, R. "*Progrès dans la Technique de la Métallographie Microscopique.*" (Actualités Scientifiques et Industrielles 301.) 8vo. pp. 58. Paris, 1935: Hermann et Cie. (Price 12 francs.)

This monograph is the first of a series published under the direction of Albert Portevin, collectively entitled "Métallurgie et Métallographie." In his preface to the series, Professor Portevin directs attention to the

publication of the more exhaustive treatises, often compiled by several collaborators, which are essential in order to provide full and comprehensive data for the specialist. For more general consumption, there appears the need for more concise expositions which will afford a fair perspective of the subject in question. This objective is particularly acceptable, and will appeal to all who desire to appreciate current trends, other than their own specialisations, and have not the time to consult the original literature or the treatises mentioned above.

The present monograph attempts a survey in 46 pages (with line drawings) of progress in practical metallography. Chapter I. deals with the preparation and polishing of metallic specimens for micro-examination. Chapter II. outlines optical systems used, lenses, and various methods of illumination, including the several types of vertical, oblique, dark field and polarised light illuminators. Mechanical details of the layout of metallographical equipment for visual and photographic work are also described. A final chapter very briefly discusses future possibilities in the use of the micro-cinematograph, photo-electric auxiliaries and illumination by wave-lengths other than those of visual light. The author has ably succeeded in providing a neat and concise survey of the subject. At the same time most metallographers would further appreciate the availability of a more comprehensive treatise alternative to the somewhat scattered data now available in many text-books and original papers.

I. G. SLATER.

GOLDSZTAUB, S. "*Quelques Idées Actuelles sur la Structure des Métaux et des Alliages.*" (Actualités Scientifiques et Industrielles 422.) 8vo. pp. 39. Paris, 1936: Hermann et Cie. (Price 12 francs.)

The second monograph of "Métallurgie et Métallographie" summarises the present position regarding certain of the more fundamental properties of metals, and its publication coincided with that of Hume-Rothery's recent monograph "The Structure of Metals and Alloys." The substance of this monograph is essentially a brief repetition and discussion of the work of W. H. and W. L. Bragg, Dehlinger and Hume-Rothery (earlier publications), and deals with the crystalline structure of pure metals, the relationship between crystalline structure, the periodic system and atomic radius, and the study of alloys.

I. G. SLATER.

HEDGES, E. S. "*Protective Films on Metals.*" Second Edition, Revised and Enlarged. Being Volume Five of a Series of Monographs on Applied Chemistry under the Editorship of E. H. Tripp. 8vo. pp. xv + 397. Illustrated. London, 1937: Chapman and Hall, Ltd. (Price 21*s.*)

For the purpose of this book the term "protective films" is used in its widest sense to denote all natural and artificial films or coatings which serve to increase the corrosion resistance of metals, and not in the narrower sense of signifying the natural self-healing films formed under certain conditions. The first edition was published in 1932, and during the five years that have since elapsed there has been considerable progress in the scientific study of protective films and their practical application. In revising the work for the second edition, particular attention has been given to practical developments, and an effort has been made to increase the industrial importance of the book.

As the importance of protective films arises from their bearing on corrosion, the first chapter is devoted to a brief account of the mechanism of this. The next three chapters are concerned with the self-healing protective films formed on exposure to air and immersion in certain liquid media. Attention is then given to both natural and artificially produced films, first to the scientific aspects of anodic film formation, and then to the practical applications of oxide and similar films produced anodically and by other means. Here such processes as coslettising, parkerising, bonderising, anodic oxidation, &c., and such materials as stainless steel and aluminium brass are discussed. The next four chapters are concerned with the protective metallic films produced by hot-dipping, electroplating, spraying and cementation, respectively. In these chapters tinning, galvanising, and hot-dipping in aluminium and lead, electroplating with copper, brass, bronze, nickel, chromium, tin, lead, cadmium and rhodium, methods of spraying and the applications of the process, and sherardising, chromising, calorising and the Follsain process are dealt with. The penultimate chapter is concerned with miscellaneous protective metallic coating, and the last with protection by means of paints, lacquers and enamels. The book may be described as essentially a work on protection against corrosion. It deals with the conditions under which this is developed naturally and with most of the methods available for producing protective films or coatings.

J. M. ROBERTSON.

HERZOG, E. "*Les Méthodes d'Essai de Corrosion des Métaux et Alliages.*" (Actualités Scientifiques et Industrielles 437.) 8vo. pp. 78. Paris, 1936: Hermann et Cie. (Price 15 francs.)

The third monograph of this series summarily deals with theoretical aspects of corrosion phenomena and methods for corrosion testing and evaluation. An amazing amount of useful information and data has been compressed, in a systematic manner, into four short chapters. A brief résumé of theoretical aspects is followed by two chapters which deal respectively with indirect methods and direct methods for evaluating corrosion effects. Indirect methods are based on electrochemical tests and measurements, whilst the direct methods include visual and optical examination, loss in weight, changes in electrical resistivity, strength properties of the metal, &c. A final chapter outlines several of the more widely used practical methods for making corrosion tests, such as field tests in various corrosive environments and laboratory tests. This monograph will prove of interest and value to everyone who is concerned with corrosion problems and corrosion tests, and will form a useful addition to the rapidly growing text-book literature available on corrosion phenomena generally.

I. G. SLATER.

KINZEL, A. B., and W. CRAFTS. "*The Alloys of Iron and Chromium. Vol. I. Low-Chromium Alloys.*" (Alloys of Iron Research, Monograph Series.) 8vo. pp. xv + 537. Illustrated. London, 1937: McGraw-Hill Publishing Co., Ltd. (Price 36*s.*)

This volume is the ninth of the series of monographs on iron alloys and the first of two volumes devoted to the iron-chromium alloys. The volumes already published deal with the principles of phase

diagrams, the metal iron, and the alloys of iron with carbon, copper, tungsten, silicon and molybdenum. Five more volumes, which deal respectively with high-chromium alloys, iron-nickel, iron-vanadium, iron-manganese, and cast iron, are in course of preparation, and the complete series will thus consist of fourteen volumes. The sponsors of the scheme, the various bodies that have given financial support and the authors of the several volumes are to be congratulated on the excellent way in which this immense work now nearing completion has been carried out, for in thus surveying the very extensive literature and assembling the more important information in a readily available form they have made a substantial contribution to the advancement of metallurgical science. If work of this kind was undertaken more frequently it would make it easier for metallurgists to obtain a general view of their subject and assist in counteracting the tendency towards excessive specialisation. Even this series of volumes, which constitutes a concise survey of the literature, is, however, a very bulky work, and a further service would be rendered if it were possible to prepare a fifteenth volume giving a general survey of the whole field.

The present volume is the first part of a review and summary of published information and available unpublished data relating to the constitution and structure of iron-chromium and iron-chromium-carbon alloys, and to the properties, uses and treatment of steels and cast irons containing chromium. So far as the steels and cast irons containing chromium are concerned, this volume is restricted to those containing less than 10%; those containing more, *i.e.*, the stainless and heat-resisting alloys, will be dealt with in a second volume. In the preliminary survey of the literature, 9,000 technical papers and articles were assembled, and from this list 478 were selected for detailed study. The volume is largely based on these and on such unpublished information as was available. In this, as in other volumes of the series, great care has been taken to include as much as possible of the information available, to arrange it in logical order and to deal with it simply. Furthermore, the practice of concluding each chapter with a statement of the conclusions reached by the authors after considering the information presented is continued. After an introductory chapter devoted to the history of chromium steels, and the sources, preparation and properties of chromium and ferro-chromium, the iron-chromium and iron-chromium-carbon alloy systems are considered. Following this, two chapters deal respectively with transformations in chromium steels and the general effect of chromium in iron and steel. The remaining eight chapters are concerned with steels and cast irons containing less than 10% of chromium. Attention is first given to the manufacture, treatment and properties of plain low-chromium steels; then the effects of manganese, silicon, nickel, copper, molybdenum, vanadium and tungsten are considered. After this, chromium tool- and special-purpose steels (*i.e.*, nitriding, armour-plate and magnet) containing less than 3·5% are dealt with, and the last two chapters are concerned respectively with cast irons and steels containing from 4 to 10% of chromium.

J. M. ROBERTSON.

ROLFE, R. T. "*Steels for the User.*" 8vo. pp. ix + 280. London, 1937: Chapman and Hall, Ltd. (Price 21*s.*)

This volume is based on a series of articles which appeared in *The Iron and Steel Industry* between 1934 and 1937. In response to a number of requests, these articles have now been republished in book form, and the opportunity has been taken of revising the text and adding new matter and figures. As indicated by the title and explained in the preface, the object of the work is to provide engineers

and other users with the knowledge necessary to enable them to exercise a greater discrimination in the selection of the steels they use for different purposes. Several books dealing with steel and other metals from this point of view have already been written, and it is surprising that there have not been more, for, unlike metallurgists, engineers have not the time nor the facilities for studying the subject as it is presented and developed in journals and periodicals, and consequently must depend on books for the information they require. As the author points out, existing books have mainly been written by scientific men who cannot be expected to see the subject from the standpoint of the user, and the present work, which has been prepared by one in close contact with the use of steel, should be of interest to engineers and others. Unfortunately it is not easy to draw a sharp line between manufacturers and users, nor to separate the information of importance to the former from that which interests the latter. An understanding of the steel-making operations is clearly of paramount importance to those concerned with the manufacture of steel, and of much less interest to those who use it, but hot- and cold-working, heat treatment, machining, welding, surface treatment, &c., are subjects that concern both parties, and the same applies to information bearing on the effect of composition in relation to behaviour in treatment, tests and service. A comprehensive book prepared with the object of providing a detailed account of all that pertains to the intelligent use of steel would be a work of some magnitude, and anything less than this must be selective. In the present volume this selection has been exercised so as to restrict it to a description of the properties, testing, heat treatment and selection of carbon steels. Thus the first chapter deals with tension, bend and impact testing, the second with various specifications for carbon steels and the effect of carbon content on mechanical properties. In the third chapter the iron-carbon diagram and its implications are described briefly, and the effects of silicon, sulphur, phosphorus and manganese are considered. This chapter concludes with a short account of the solidification of steel ingots. The fourth chapter consists of a discussion of bright and free-cutting steels, and the next four are devoted to heat treatment. These deal respectively with theoretical considerations, heat treatment of low-carbon and high-carbon steels, and finally with case-hardening and similar treatments. Testing is further considered in the ninth and tenth chapters, which are devoted respectively to the use of steels at elevated temperatures and fatigue testing. The last chapter is concerned with the general principles of selection. Good practical information is provided on the effect of heat treatment on mechanical properties and on the relations between test results and behaviour in service. The practical sections are undoubtedly good, but the statement in the preface that the practical features are scientifically explained is hardly justified, and in view of the fact that so much of the book is concerned with heat treatment and its effect on microstructure and properties, more attention should have been given to describing the changes that occur in steel during heating and cooling and the effects of the rates at which these operations are performed. It is true that these phenomena have been described over and over again, and the author has therefore chosen to deal with them very briefly in order to leave more space for other things. Nevertheless the book will probably be read by many who are not previously acquainted with the iron-carbon diagram and all that it implies, and who will therefore fail to appreciate much of the subject matter.

J. M. Robertson.

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